CHAPTER 4

The Study Results

4.1 Assessment of reliability index distribution system

The data of existing networks and the results of reliability indices described in chapter 3, the SAIFI, SAIDI and CAIDI in 2013 will be 5.83 times/customer/year, 658.95 hours/customer/year and 112.89 hours/year, respectively.

Use DIgSILENT Power Factory software to analyze reliability on the primary distribution network of Vientiane capital in cases improvement of the distribution system. Analysis results are shown tables from 4.2

4.2 Network elements

This thesis has a situation that obtaining the specific detail, for DIgSILENT Power Factory program, is very difficult. Because the project is located in the Vientiane capital and there are no complete data available for the Vientiane power distribution system and equipment even in the distribution system. Therefore, the distribution transformers are included in the simulation of the network. Also, some devices such as, fuses, re-closers, circuit breakers, switches, and etc., are included in the network simulation. Since the main point of the research is outage duration and the voltage drop in the MV level, the number of the distribution transformers and protection devices do have a significant effect on the system simulation results.

For the feeders, as main factor causing power outage in the system, the zero sequence and negative sequence impedances and admittances and size of the conductors, used in DIgSILENT Power Factory program, are collected from the system

simulation. Table 4.1 shows bare conductors sizes used of the substations in the Vientiane Capital electric network for overhead MV distribution lines. Similarly, contains specifications (Z_1 is positive sequence impedance and Z_0 is zero sequence impedance).

Table 4.1 Conductors specifications used for overhead lines of the substations in Vientiane capital

Equipment ID	Size (mm^2)	Z_1 (Ω/km)		Z_0 (Ω/km)		Current (kA)
		R1 (ohm/km)	X1 (ohm/km)	R0 (ohm/km)	X0 (ohm/km)	
ACSR	25	1.1380	0.4818	1.3158	1.9333	0.125
ACSR	35	1.1100	0.4129	1.2582	1.6397	0.129
ACSR	70	0.5560	0.3912	0.7024	1.6180	0.195
ACSR	150	0.1830	0.3281	0.3312	1.5550	0.335
ACSR	185	0.1882	0.3068	0.3364	1.5336	0.535
ACSR	240	0.1343	0.3179	0.2825	1.5448	0.560
PIC	35	0.8260	0.4199	0.9742	1.6467	0.149
PIC	50	0.7831	0.3851	0.9742	1.6467	0.186
PIC	70	0.4430	0.3733	0.5912	1.6001	0.237
PIC	95	0.3834	0.2844	0.5316	1.7472	0.279
PIC	120	0.2530	0.3553	0.5361	1.7472	0.321
PIC	150	0.2060	0.3432	0.3542	1.5700	0.365
PIC	185	0.1640	0.3361	0.3122	1.5629	0.429
SAC	25	1.2000	0.4302	1.3482	1.6570	0.429
SAC	35	0.8680	0.4199	1.0162	1.6467	0.150
SAC	50	0.6410	0.4085	0.7892	1.6354	0.180
SAC	70	0.4430	0.3733	0.5912	1.6001	0.180
SAC	95	0.3200	0.3631	0.4682	1.5899	0.275
SAC	120	0.2530	0.3553	0.4012	1.5822	0.315
SAC	150	0.2060	0.3492	0.3542	1.5761	0.360
SAC	180	0.1640	0.3361	0.3122	1.5629	0.415
SAC	240	0.1250	0.3270	0.2732	1.5538	0.490

4.3 Medium voltage of Vientiane Capital

The MV system in Vientiane capital is composed of Maximum Segment Size (MSS) system and Maximum Segment Hoch (MSH) system. The MSS system composed of MV single circuit feeders in radial form is strung from directly from 115 KV / 22 KV substations or 22 KV switching stations to power supply areas. The MSH system is a system of interconnections among 115 kV / 22kV substations or 22kV switching station mainly with 240 mm^2 x 2 circuits.

4.4 Loads

The distribution system for simulation is considered as spot loads have total transformers 1,473 units that are distributed to consumers. The loads are composed of seven types: residential, governmental, office, industrial, agriculture, embassy and business as seen in appendix A.

Phontong substation is 115kV/22kV, has four transformers and 4x50 MVA of size. It has five feeders; the name of feeders was MSS 5.1, MSS 5.2, MSS 5.3, MSS 5.4 and MSS 5.5 as shown in Figure 4.1.

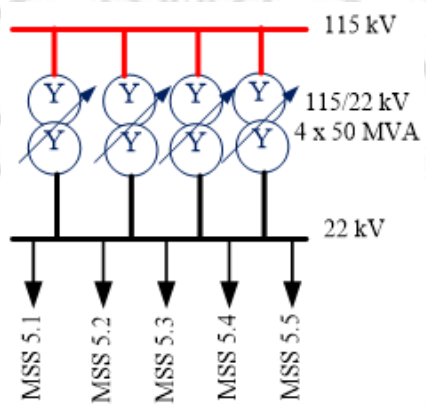

Figure 4.1 Single line diagram of the distribution system in Phontong substation.

Thanaleng substation is 115kV/22kV, has three transformers and 3x30 MVA of size. It has seven feeders; the name of feeders was MSS 6.1, MSS 6.2, MSS 6.4, MSS 6.5, MSS 6.6, MSS 6.7 and MSS 6.8 as shown in Figure 4.2.

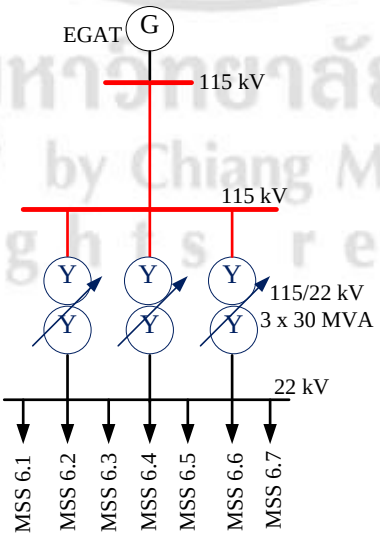

Figure 4.2 Single line diagram of the distribution system in Thanaleng substation.

ThaNgone substation is 115kV/22kV, has one transformer and 1x30 MVA of size. It has four feeders; the name of feeders was MSS 8.1, MSS 8.2, MSS 8.3 and MSS 8.4 as shown Figure 4.3.

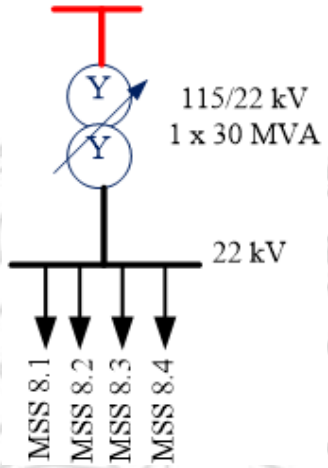

Figure 4.3 Single line diagram of the distribution system in ThaNgon substation.

Khoksa-at the substation is 115kV/22kV, has tree transformers and 1x30 MVA, 2x22 MVA of size. It has six feeders; the name of feeders was MSS 9.1, MSS 9.2, MSS 9.3, MSS 9.4, MSS 9.5 and MSS 9.6 as shown in Figure 4.4.

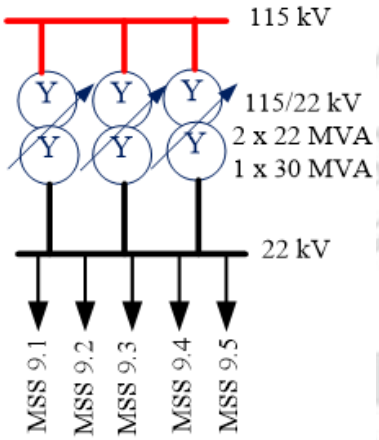

Figure 4.4 Single line diagram of the distribution system in Khoksa-at substation.

Naxaythong substation is 115kV/22kV, has two transformers and 2x30 MVA of size. It has four feeders; the name of feeders was MSS 10.1, MSS 10.2, MSS 10.3 and MSS 10.4 as shown in Figure 4.5.

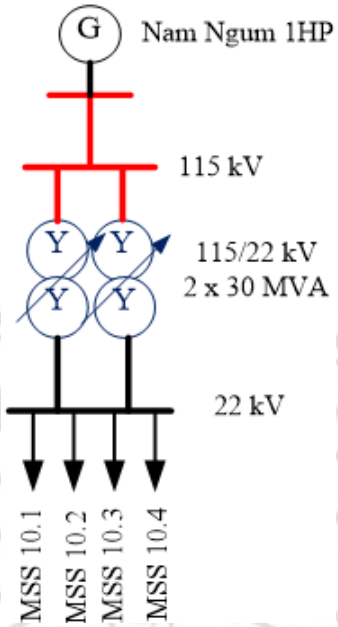

Figure 4.5 Single line diagram of the distribution system in Naxaythong substation.

4.5 Analyses reliability indices

The total peak loads on the MSS system were 255.57 MW and the total length was 1,192.2 km in the case with the situation in Vientiane capital. The reliability improvement is considered from reliability in each substation and input to software analysis that shown in Table 4.2; Naxaythong substation has reliability indices higher more than other substation because, the outage duration more than other substation also, the number of customs interruption were more.

Table 4.2: The results of reliability index calculation of MSS system in 2013

Name of substation	ID	Name of feeder	Total load		Length	Outage duration	SAIFI	SAIDI
			MW	PF%	km	hour	(t/customer/y)	(h/customer/y)
Phonetong	1	MSS 5.1	14.26	88	9.8	1.02	4.05	4.13
	2	MSS 5.2	12.41	88	18	1.02	4.24	4.32
	3	MSS 5.3	9.62	86	29	1.02	5.12	5.22
	4	MSS 5.4	3.48	87	32.2	1.04	5.77	6.00
	5	MSS 5.5	6.14	88	6.1	1.05	5.06	5.32

Table 4.2: The results of reliability index calculation of MSS system in 2013 (Continued)

Name of substation	ID	Name of feeder	Total load		Length	Outage duration	SAIFI	SAIDI
			MW	PF%	km	hour	(t/customer/y)	(h/customer/y)
Thanaleng	6	MSS 6.1	7.88	88	14.2	5.10	3.71	18.96
	7	MSS 6.2	0.81	88	4.9	5.70	3.76	21.44
	8	MSS 6.3	7,424	87	44.6	5.00	3.73	18.67
	9	MSS 6.4	6.14	88	86.3	5.30	3.95	20.98
	10	MSS 6.5	8.69	88	43.8	6.89	4.06	28.02
	11	MSS 6.6	10.91	87	21.3	5.20	4.59	23.87
	12	MSS 6.7	8.81	87	31.3	3.88	4.81	18.702
Tha-ngon	13	MSS 8.1	5.33	89	85.9	4.58	4.09	18.74
	14	MSS 8.2	6.85	88	23.5	4.50	3.71	16.72
	15	MSS 8.3	6.85	88	75.0	4.40	3.64	16.04
	16	MSS 8.4	0.22	87	7.9	6.15	3.00	18.45
Khoksa-at	17	MSS 9.1	6.73	87	26.0	2.80	3.33	9.32
	18	MSS 9.2	5.59	87	59.4	2.87	3.348	9.60
	19	MSS 9.3	14.99	84	205.8	3.27	3.51	11.47
	20	MSS 9.4	9.27	87	5.1	1.12	3.28	3.66
	21	MSS 9.5	3.96	87	1.1	2.29	2.00	4.57
	22	MSS 9.6	6.14	87	20.3	5.29	2.997	15.84
Naxaythong	23	MSS 10.1	1.04	88	18.3	7.72	11.93	92.12
	24	MSS 10.2	8.23	87	97.5	9.03	13.59	122.73
	25	MSS 10.3	7.71	86	200	7.52	15.42	115.92
	26	MSS 10.4	4.96	87	24.9	9.15	13.67	125.11
Total			**255.57**		**1,192.2**	**112.89**	**5.83**	**658.95**

4.6 Improved of reliability indices

There are a number of ways to improve reliability, however, it is economically viable to consider all the possibilities due to dispersed customer locations, low energy consumption and too less number of customers connected to the feeder. In this case study area, auto re-closers and load disconnect switching were proposed. It is placed at a location which gives minimum SAIFI and SAIDI. The alternatives were the placement of the Load break switch at different locations and the alternative which gives lowest SAIFI and SAIDI.

The case study of reliability improvement will see value, index SAIFI and SAIDI are variants of each case study, which considered of reliability indices each case as seen distinction for adding equipment prevent by Load Break Switches (LBS), re-closer, and Disconnect Switching (DS). It is affected for reliability indices on the distribution system. Indices, which are used to perform reliability values of the power system, are the frequency and interruption duration. Then, study of reliability indices to the right area on investment and system planning.

4.6.1 Switching optimization

The switching optimization with utilizing the interconnection could to reduce affect customer from a due damage outage; however, some of the heavily loaded sections were still remaining. Some feeders in all substations are connected by DS, LBS and re-closer seen below.

4.6.1.1 Installing DS

1. Phontong substation

Phontong substation has five feeders, the name of feeders are MSS 5.1, MSS 5.2, MSS 5.3, MSS 5.4 and MSS 5.5. Then, adding 2 sets of DS in each feeder such as: S5_F1_10, S5_F1_66, S5_F2_61, S5_F2_78, S5_F3_280, S5_F3_377, S5_F4_250, S5_F4_301, S5_F5_280 and S5_F5_580, as shown in table 4.3 and Figure 4.6.

Table 4.3 DS installation at Phontong substation

Feeders	Section Id 1	Section Id 2
MSS 5.1	S5_F1_10	S5_F1_66
MSS 5.2	S5_F2_61	S5_F2_78
MSS 5.3	S5_F3_280	S5_F3_377
MSS 5.4	S5_F4_250	S5_F4_301
MSS 5.5	S5_F5_280	S5_F5_580

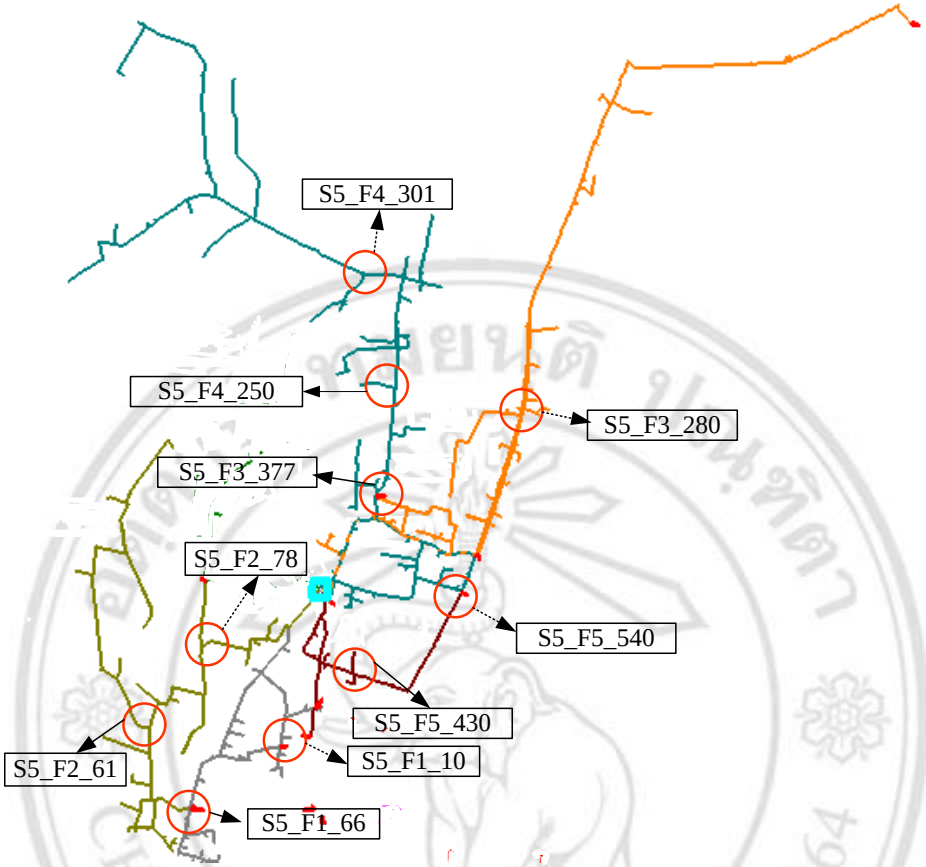

Figure 4.6 Location of DS connected point feeder of Phontong substation.

Installation of Switching on suitable locations of DS in each feeder at Phontong substation for reduce reliability index in the distribution system as shown in table 4.4.

Table 4.4 Switching operations of Phontong substation

Section Id	Action	Load transferred			SAIFI	SAIDI
		From	To	kW	(time/customer/year)	(hour/customer/year)
S5_F1_10	Open	MSS5_1	MSS5_2	14,245.40	3.55	3.62
S5_F2_78	Close					
S5_F3_377	Open	MSS5_3	MSS5_4	9,435	3.89	3.96
S5_F4_301	Close					
S5_F4_350	Open	MSS5_4	MSS5_5	3,297	4.25	4.25
S5_F5_230	Close					
S5_F2_61	Open	MSS5_2	MSS5_1	12,117	3.84	3.92
S5_F1_66	Close					
S5_F5_540	Open	MSS5_5	MSS5_3	6,039	4.20	4.21
S5_F3_280	Close					

The table 4.5 by adding 10 sets of DS in Phontong substation, so that the value of SAIFI has tendency to decrease 3.91 from 4.78 (SAIFI=0.87 time/customer/year), Also, SAIDI and CAIDI are decreasing from 24.63 to 19.76 (4.86 hour/ customer /year) and 5.15 to 5.06 (0.09 hour/year), respectively.

Table 4.5: Summary of reliability indices in Phontong substation

Feeders		Load kW	SAIFI (time/customer/year)	SAIDI (hour/customer/year)	CAIDI (hour/year)
MSS 5.1	Before	14,268.40	4.05	4.13	1.02
	After	14,245.16	3.55	3.62	1.02
Change			**0.50**	**0.51**	-
MSS 5.2	Before	12,411.9	4.24	4.32	1.02
	After	12,117.08	3.84	3.92	1.02
Change			**0.40**	**0.40**	-
MSS 5.3	Before	9,6281.1	5.12	5.22	1.02
	After	9,435	3.89	3.96	1.02
Change			**1.23**	**1.26**	-
MSS 5.4	Before	3,480	5.77	6.00	1.18
	After	3,297	4.25	4.56	1.00
Change			**1.52**	**1.44**	**0.18**
MSS 5.5	Before	6,148	5.06	5.32	1.04
	After	6,039	4.20	4.21	1.00
Change			**0.86**	**1.11**	**0.04**
Total	Before	45,9364	4.78	24.63	5.15
	After	45,133.24	3.91	19.76	5.06
Change			**0.87**	**4.86**	**0.09**

2. Thanaleng substation

Thanaleng substation has seven feeders, the name of feeders are MSS 5.1, MSS 5.2, MSS 5.3, MSS 5.4 and MSS 5.5. After that, adding 4 sets of DS in each feeder such as: S6_F4_301, S6_F5_275, S6_F6_280 and S6_F7_156, as shown in table 4.6 and Figure 4.7.

Table 4.6 DS installation at Thanaleng substation

Feeders	Section Id
MSS 6.4	S6_F4_301
MSS 6.5	S6_F5_275
MSS 6.6	S6_F6_280
MSS 6.7	S6_F7_156

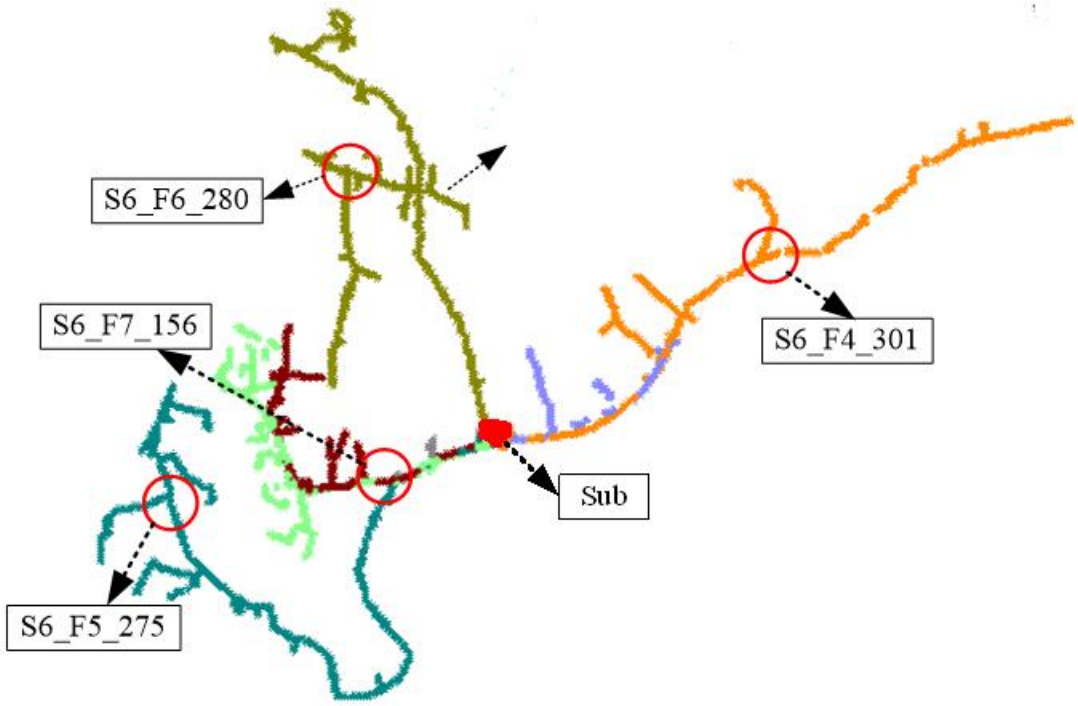

Figure 4.7 Location of DS connected point feeder of Thanaleng substation.

Installation of switching on suitable locations of DS in each feeder at Thanaleng substation for reduce reliability index in the distribution system as shown in table 4.5.

Table 4.7 Switching operations of Thanaleng substation

Section Id	Action	Load transferred			SAIFI	SAIDI
		From	To	kW	(time/customer/year)	(hour/customer/year)
S6_F3_277	Open	MSS 6_3	MSS 6_4	1,260	3.28	16.36
S6_F4_301	Close					
S6_F4_250	Open	MSS 6_4	MSS 6_5	2,125	3.38	16.61
S6_F5_2	Close					
S6_F5_54	Open	MSS 6_5	MSS 6_6	2,656	3.43	23.26
S6_F6_280	Close					
S6_F6_120	Open	MSS 6_6	MSS 6_7	3,250	3.59	18.47
S6_F7_156	Close					

The table 4.8 by adding 4 sets of DS in Thanaleng substation so that the value of SAIFI has tendency to decrease 3.48 from 4.33 (SAIFI=0.85 time/customer/year), Also, SAIDI and CAIDI are decreasing from 160.50 to 126.60 (33.90 hour/ customer /year) and 37.07 to 36.37 (0.70 hour/year), respectively.

Table 4.8: Summary of reliability indices in Thanaleng substation

Feeders		Load kW	SAIFI (time/customer/year)	SAIDI (hour/customer/year)	CAIDI (hour/year)
MSS 6.1	Before	78,888	3.71	18.96	5.09
	After	77,464	3.29	16.69	5.07
Change			**0.42**	**2.27**	**0.02**
MSS 6.2	Before	812	3.76	21.44	5.69
	After	795	3.29	18.60	5.65
Change			**0.47**	**2.84**	**0.04**
MSS 6.3	Before	7,424	3.73	18.67	5.00
	After	7,379	3.28	16.36	4.98
Change			**0.45**	**2.31**	**0.02**
MSS 6.4	Before	6,148.1	3.95	20.98	5.29
	After	6,096	3.38	16.61	4.91
Change			**0.57**	**4.37**	**0.38**
MSS 6.5	Before	8,699.9	4.06	28.02	6.89
	After	8,554	3.43	23.26	6.78
Change			**0.63**	**4.76**	**0.11**
MSS 6.6	Before	10,915.1	4.59	23.87	5.19
	After	10,355	3.59	18.47	5.14
Change			**1.00**	**5.40**	**0.05**
MSS 6.7	Before	8,815.9	4.81	18.70	3.88
	After	8,736	3.58	13.70	3.81
Change			**1.23**	**5.00**	**0.07**
Total	Before	121,730	4.33	160.50	37.07
	After	119,379.04	3.48	126.60	36.37
Change			**0.85**	**33.90**	**0.70**

3. ThaNgon substation

ThaNgon substation has four feeders, the name of feeders are MSS8.1, MSS8.2, MSS8.3 and MSS8.4. So that, adding 4 sets of DS in each feeder such as: S8_F1_135, S8_F2_347, S8_F3_283 and S8_F4_9, as shown in table 4.9 and Figure 4.8.

Table 4.9 DS installation at ThaNgon substation

Feeders	Section Id
MSS 8.1	S8_F1_135
MSS 8.2	S8_F2_347
MSS 8.3	S8_F3_283
MSS 8.4	S8_F4_9

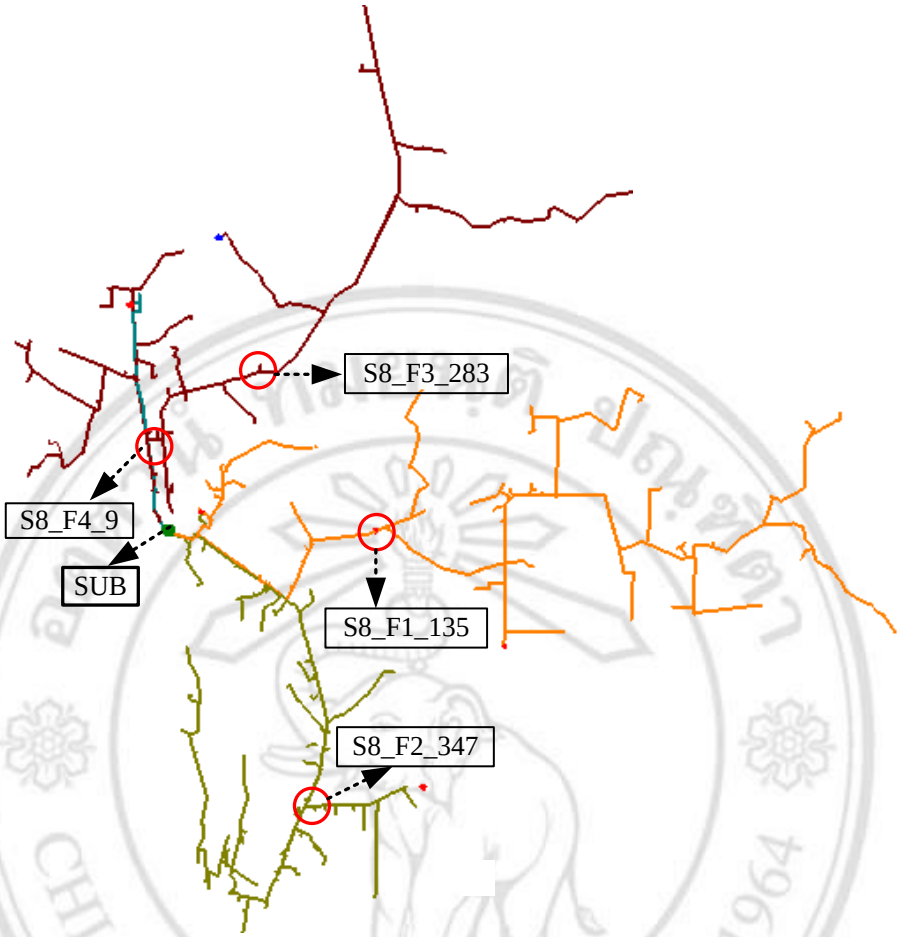

Figure 4.8 Location of DS connected point feeder of ThaNgon substation.

Installation of Switching on suitable locations of DS in each feeder at ThaNgon substation for reduce reliability index in the distribution system as shown in table 4.10.

Table 4.10 Switching operations of ThaNgon substation

Section Id	Action	Load transferred			SAIFI	SAIDI
		From	To	kW	(time/customer/year)	(hour/customer/year)
S8_F1_135	Open	MSS8_1	MSS8_2	4,874.29	3.50	14.65
S8_F2_106	Close					
S8_F2_347	Open	MSS8_2	MSS8_3	5,629.34	3.50	14.65
S8_F3_98	Close					
S8_F3_238	Open	MSS8_3	MSS8_4	5,625.05	3.30	13.57
S8_F4_16	Close					
S8_F4_9	Open	MSS8_4	MSS8_1	178.05	2.81	11.70
S8_F1_110	Close					

The table 4.11 by adding 4 sets of DS in ThaNgon substation so that the value of SAIFI has tendency to decrease 3.44 from 4.79 (SAIFI=0.35 time/customer/year), Also, SAIDI and CAIDI are decreasing from 74.51 to 57.31 (17.20 hour/ customer /year) and 19.63 to 16.20 (3.43 hour/year), respectively.

Table 4.11: Summary of reliability indices in ThaNgon substation

Feeder		Load kW	SAIFI (time/customer/year)	SAIDI (hour/customer/year)	CAIDI (hour/year)
MSS 8.1	Before	5,333.9	4.09	18.74	4.57
	After	4,874.29	3.50	14.65	4.17
Change			**0.59**	**4.09**	**0.40**
MSS 8.2	Before	6,852.9	3.71	16.72	4.50
	After	5,629.34	3.50	14.65	4.17
Change			**0.21**	**2.07**	**0.33**
MSS 8.3	Before	6,852.9	3.64	16.04	4.39
	After	5,625.05	3.30	13.57	4.11
Change			**0.34**	**2.47**	**0.28**
MSS 8.4	Before	221	3.00	18.45	6.15
	After	178.05	2.81	11.70	4.15
Change			**0.19**	**6.75**	**2.00**
Total	Before	19,260.70	3.79	74.51	19.63
	After	16,306.73	3.44	57.31	16.20
Change			**0.35**	**17.20**	**3.43**

4. Khoksa-at substation

Khoksa-at substation has six feeders, the name of feeders are MSS 9.1, MSS 9.2, MSS 9.3, MSS 9.4, MSS 9.5 and MSS 9.6. Also, adding 7 sets of DS in each feeder such as: S9_F1_32, S9_F2_102, S9_F2_219, S9_F3_157, S9_F3_232, S9_F4_42 and S9_F6_35, as shown in table 4.12 and Figure 4.9.

Table 4.12 DS installation at Khoksa-at substation

Feeders	Section Id
MSS 8.1	S8_F1_135
MSS 8.2	S8_F2_347
MSS 8.3	S8_F3_283
MSS 8.4	S8_F4_9

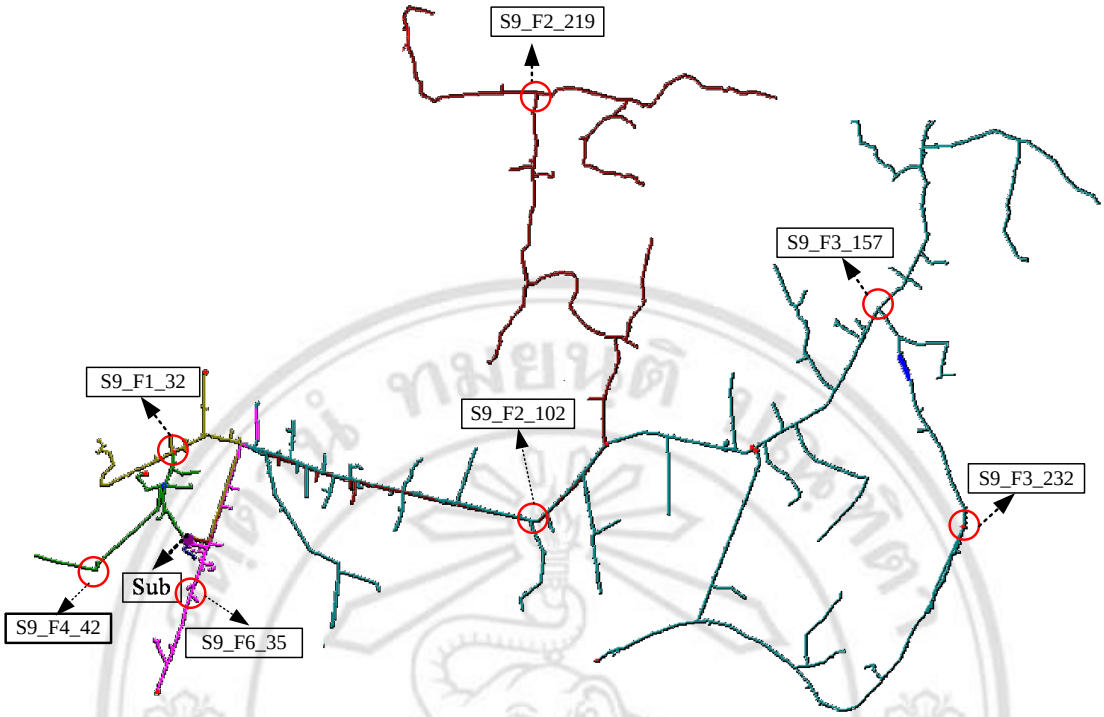

Figure 4.9 Location of DS connected point feeder of Khoksa-at substation.

Installation of Switching on suitable locations of DS in each feeder at Khoksa-at substation for reduce reliability index in the distribution system as shown in table 4.13.

Table 4.13 Switching operations of Koksa-at substation

Section Id	Action	Load transferred			SAIFI	SAIDI
		From	To	kW	(time/customer/year)	(hour/customer/year)
S9_F1_32	Open	MSS9_1	MSS9_4	6,545	2.81	7.34
S9_F4_56	Close					
S9_F2_102	Open	MSS9_2	MSS9_3	5,484	2.81	7.34
S9_F3_132	Close					
S9_F3_157	Open	MSS9_3	MSS9_5	14,023	3.30	10.80
S9_F5_76	Close					
S9_F4_42	Open	MSS9_4	MSS9_6	9,058	2.80	3.09
S9_F6_69	Close					
S9_F5_219	Open	MSS9_5	MSS9_1	3,842	1.66	3.70
S9_F1_25	Close					
S9_F6_35	Open	MSS9_6	MSS9_2	6,071	2.88	14.88
S9_F2_250	Close					

The table 4.14 by adding 4 sets of DS in Khoksa-at substation so that the value of SAIFI has tendency to decrease 2.95 from 3.04 (SAIFI=0.09 time/customer/year), Also, SAIDI and CAIDI are decreasing from 58.79 to 50.12 (8.67 hour/ customer /year) and 17.62 to 16.98 (0.64 hour/year), respectively.

Table 4.14: Summary of reliability indices in Khoksa-at substation

Feeders		Load kW	SAIFI (time/customer/year)	SAIDI (hour/customer/year)	CAIDI (hour/year)
MSS 9.1	Before	6,737	3.33	9.32	2.80
	After	6,545	2.81	7.34	2.61
Change			**0.52**	**1.98**	**0.19**
MSS 9.2	Before	5,590	3.34	9.60	2.86
	After	5,484	2.81	7.34	2.61
Change			**0.53**	**2.25**	**0.25**
MSS 9.3	Before	14,996	3.51	11.47	3.27
	After	14,023.02	3.30	10.80	3.27
Change			**0.21**	**0.67**	**-**
MSS 9.4	Before	9,279.9	3.28	3.66	1.11
	After	9,058	2.80	3.09	1.10
Change			**0.48**	**0.57**	**0.01**
MSS 9.5	Before	3,969	2.00	4.57	2.28
	After	3,842	1.66	3.70	2.22
Change			**0.34**	**0.87**	**0.06**
MSS 9.6	Before	6,148	2.99	15.84	5.28
	After	6,071	2.88	14.88	5.16
Change			**0.11**	**0.96**	**0.12**
Total	Before	46,719.90	3.04	58.79	17.62
	After	45,023.02	2.95	50.12	16.98
Change			**0.09**	**8.67**	**0.64**

5. Naxaythong substation

Naxaythong substation has four feeders, the name of feeders are MSS 10.1, MSS 10.2, MSS 10.3 and MSS 10.4. Therefore, adding 8 sets of DS in each feeder such as: S10_F1_29, S10_F1_45, S10_F2_75, S10_F2_195, S10_F3_79, S10_F3_105, S10_F5_98 and S10_F4_155, as shown in table 4.15 and Figure 4.10.

Table 4.15 DS installation at Naxaythong substation

Feeders	Section Id
MSS 8.1	S8_F1_135
MSS 8.2	S8_F2_347
MSS 8.3	S8_F3_283
MSS 8.4	S8_F4_9

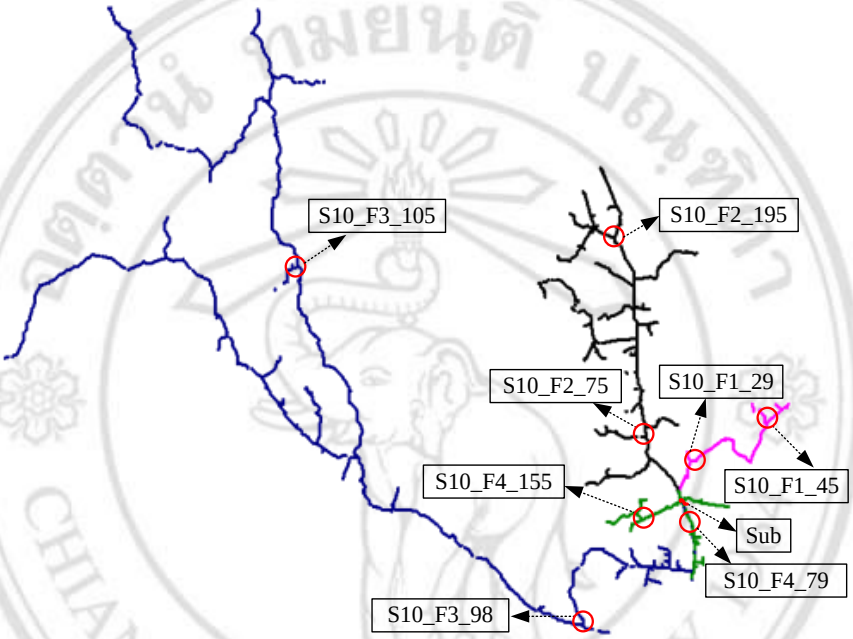

Figure 4.10 Location of DS connected point feeder of Naxaythong substation.

Installation of switching on suitable locations of DS in each feeder at Naxaythong substation for reduce reliability index in the distribution system as shown in table 4.16.

Table 4.16 Switching operations of Naxaythong substation

Section Id	Action	Load transferred			SAIFI	SAIDI
		From	To	kW	(time/customer/year)	(hour/customer/year)
S10_F1_45	Open	MSS10_1	MSS10_4	988.33	10.45	79.86
S10_F2_75	Close					
S10_F2_195	Open	MSS10_2	MSS10_3	8,179.24	10.59	94.94
S10_F3_79	Close					
S10_F4_98	Open	MSS10_4	MSS10_3	7,688.43	12.70	115.74
S10_F4_155	Close					
S10_F3_105	Open	MSS10_3	MSS10_1	7,688.43	12.72	94.86
S10_F1_29	Close					

The table 4.17 by adding 8 sets of DS in Naxaythong substation so that the value of SAIFI has tendency to decrease 11.46 from 13.95 (SAIFI=2.49 time/customer/year), Also, SAIDI and CAIDI are decreasing from 466.22 to 380.29 (85.93 hour/ customer /year) and 33.42 to 33.17 (0.25 hour/year), respectively.

Table 4.17: Summary of reliability indices in Naxaythong substation

Feeders		Load kW	SAIFI (time/customer/year)	SAIDI (hour/customer/year)	CAIDI (hour/year)
MSS 10.1	Before	1,044	11.93	92.12	7.72
	After	988.33	10.45	79.86	7.64
Change			**1.48**	**12.26**	**0.08**
MSS 10.2	Before	8,236.1	13.59	122.73	9.02
	After	8,179.24	10.59	94.94	8.96
Change			**3.00**	**27.79**	**0.06**
MSS 10.3	Before	7,716.6	15.42	115.92	7.51
	After	7,688.43	12.72	94.86	7.45
Change			**2.70**	**21.06**	**0.06**
MSS 10.4	Before	4,961	13.67	125.11	9.15
	After	4,938	12.70	115.74	9.10
Change			**0.97**	**9.37**	**0.05**
Total	Before	21,957.70	13.95	466.22	33.42
	After	21,794.40	11.46	380.29	33.17
Change			**2.49**	**85.93**	**0.25**

4.6.1.2 LBS installation

1. Phontong substation

The reliability indices enhance in Phontong substation by LBS installation 5 sets in suitable point as: S5_F1_25, S5_F2_135, S5_F3_213, S5_F4_273 and S5_F5_115 as shown in Table 4.18 and Figure 4.11.

Table 4.18 LBS installation at Phontong substation

Feeders	Section Id
MSS 5.1	S5_F1_25
MSS 5.2	S5_F2_135
MSS 5.3	S5_F3_213
MSS 5.4	S5_F4_273
MSS 5.5	S5_F5_115

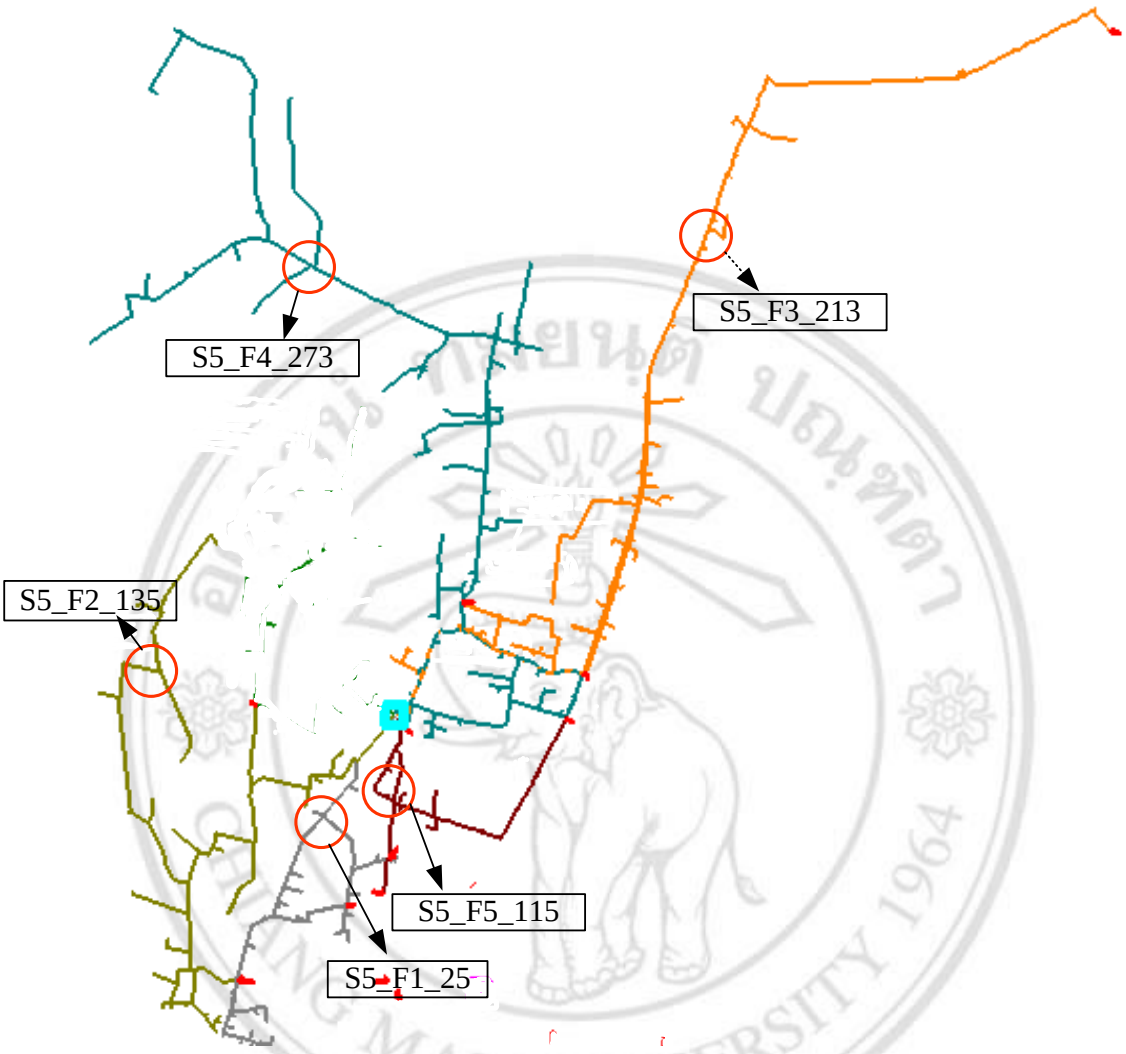

Figure 4.11 Location of installing LBS in Phontong substation.

The table 4.19 showed the reliability indices before and after adding 5 sets of re-closer in Phontong substation. The reliability indices of SAIFI, SAIDI and CAIDI after adding re-closer were decreased from 4.78 to 3.35 (0.43 time/customer/year), 24.63 to 22.17 (2.46 hour/customer/year) and 5.15 to 5.08 (0.10 hour/year), respectively.

Table 4.19 Summary of reliability indices in Phontong substation

	Load kW	SAIFI (time/customs/year)	SAIDI (hour/customs/year)	CAIDI (hour/year)
Before	45,936.40	4.78	24.63	5.15
After	45,374.06	4.35	22.17	5.08
Change		**0.43**	**2.46**	**0.10**

2. Thanaleng substation

The reliability indices enhance in Thanaleng substation by LBS installation 4 sets in suitable point as: S6_F1_78, S6_F2_198, S6_F5_128 and S6_F6_90 as shown in table 4.20 and Figure 4.12.

Table 4.20 Installing LBS in Thanaleng substation

Feeders	Section Id
MSS 6.1	S6_F1_78
MSS 6.2	S6_F2_198
MSS 6.3	S6_F5_128
MSS 6.4	S6_F6_90

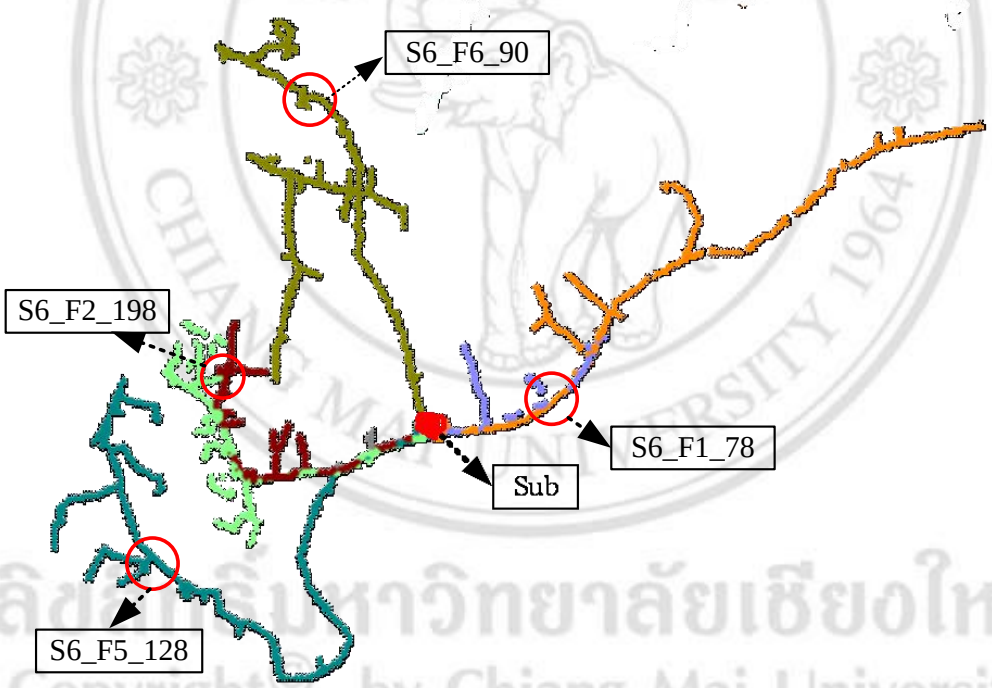

Figure 4.12 Location of installing LBS in Thanaleng substation.

The table 4.21 showed the reliability indices before and after adding 5 sets of re-closer in Thanaleng substation. The reliability indices of SAIFI, SAIDI and CAIDI after adding re-closer were decreasing from 4.33 to 3.91 (0.42 time/customer/year), 160.57 to 140.42 (20.15 hour/customer/year) and 37.07 to 35.87 (1.2 hour/year), respectively.

Table 4.21 Summary of reliability indices in Thanaleng substation

	Load kW	SAIFI (time/customs/year)	SAIDI (hour/customs/year)	CAIDI (hour/year)
Before	121,694	4.33	160.57	37.07
After	116,754.62	3.91	140.42	35.87
Change		**0.42**	**20.15**	**1.2**

3. ThaNgon substation

The reliability indices enhance in ThaNgon substation by LBS installation 3 sets in suitable point as: S8_F1_103, S8_F2_352 and S8_F3_207 as shown in table 4.22 and Figure 4.13.

Table 4.22 Installing LBS in ThaNgon substation

Feeders	Section Id
MSS 8.1	S8_F1_103
MSS 8.2	S8_F2_352
MSS 8.3	S8_F3_207

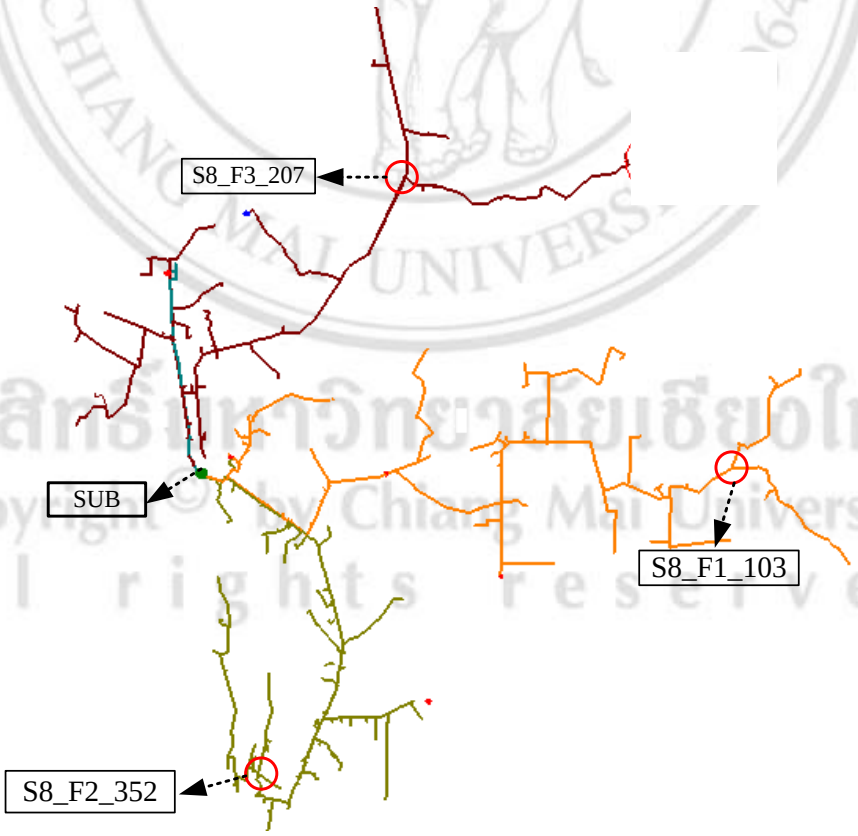

Figure 4.13 Location of installing LBS in ThaNgon substation.

The table 4.23 showed the reliability indices before and after adding 5 sets of re-closer in ThaNgon substation. The reliability indices of SAIFI, SAIDI and CAIDI after adding re-closer were decreasing from 3.79 to 3.43 (0.36 time/customer/year), 74.51 to 54.10 (20.41 hour/customer/year) and 19.63 to 15.76 (3.87 hour/year), respectively.

Table 4.23 Summary of reliability indices in ThaNgon substation

	Load kW	SAIFI (time/customs/year)	SAIDI (hour/customs/year)	CAIDI (hour/year)
Before	19,260.70	3.79	74.51	19.63
After	14,762.94	3.43	54.10	15.76
Change		**0.36**	**20.41**	**3.87**

4. Khoksa-at substation

The reliability indices enhance in Khoksa-at substation by LBS installation 5 sets in suitable point as: S9_F1_81, S9_F2_92, S9_F3_205 and S9_F4_90 as shown in table 4.24 and Figure 4.14.

Table 4.24 Installing LBS in Khoksa-at substation

Feeders	Section Id
MSS 9.1	S9_F1_81
MSS 9.2	S9_F2_92
MSS 9.3	S9_F3_205
MSS 9.4	S9_F4_90

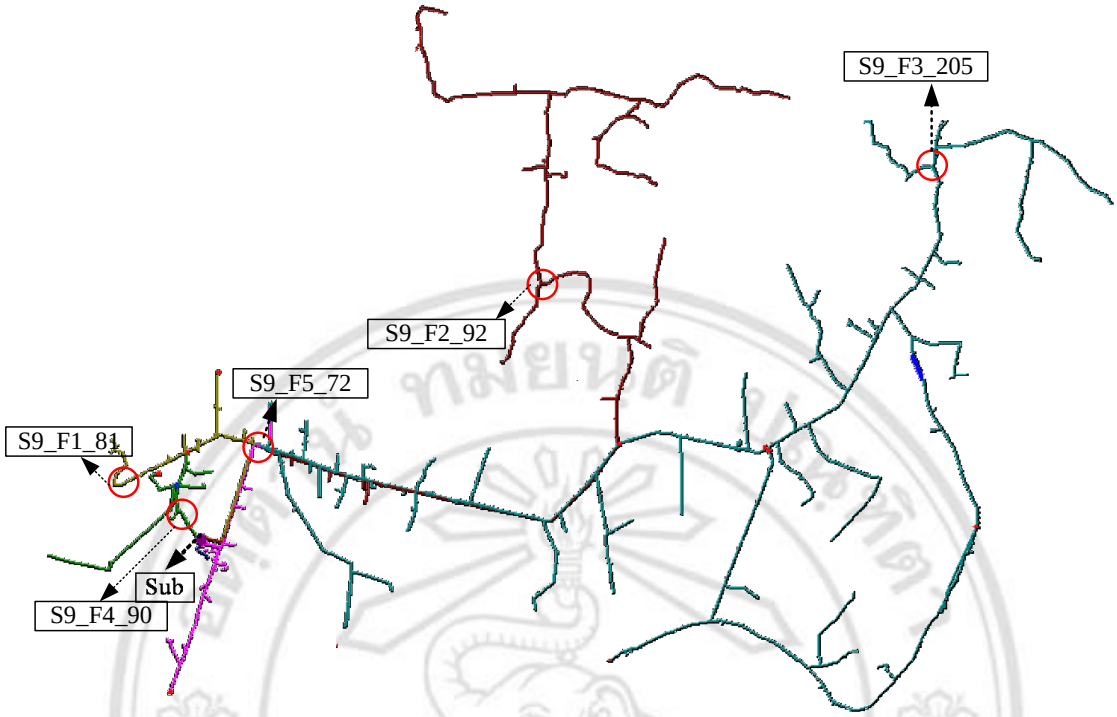

Figure 4.14 Location of installing LBS in Khoksa-at substation.

The table 4.25 showed the reliability indices before and after adding 5 sets of re-closer in Khoksa-at substation. The reliability indices of SAIFI, SAIDI and CAIDI after adding re-closer were decreasing from 3.33 to 3.00 (0.33 time/customer/year), 58.79 to 46.78 (12.01 hour/customer/year) and 17.64 to 15.55 (2.09 hour/year), respectively.

Table 4.25 Summary of reliability indices in Khoksa-at substation

	Load kW	SAIFI (time/customer/year)	SAIDI (hour/customer/year)	CAIDI (hour/year)
Before	46,719.9	3.33	58.79	17.64
After	40,131.33	3.00	46.78	15.55
Change		**0.33**	**12.01**	**2.09**

5. Naxaythong substation

The reliability indices enhancement in Naxaythong substation by LBS installation 5 sets in suitable point as: S10_F1_35, S10_F2_208, S10_F3_235 and S10_F4_113 as shown in table 4.26 and Figure 4.15.

Table 4.26 Installing LBS in Naxaythong substation

Feeders	Section Id
MSS 10.1	S10_F1_35
MSS 10.2	S10_F2_208
MSS 10.3	S10_F3_235
MSS 10.4	S10_F4_113

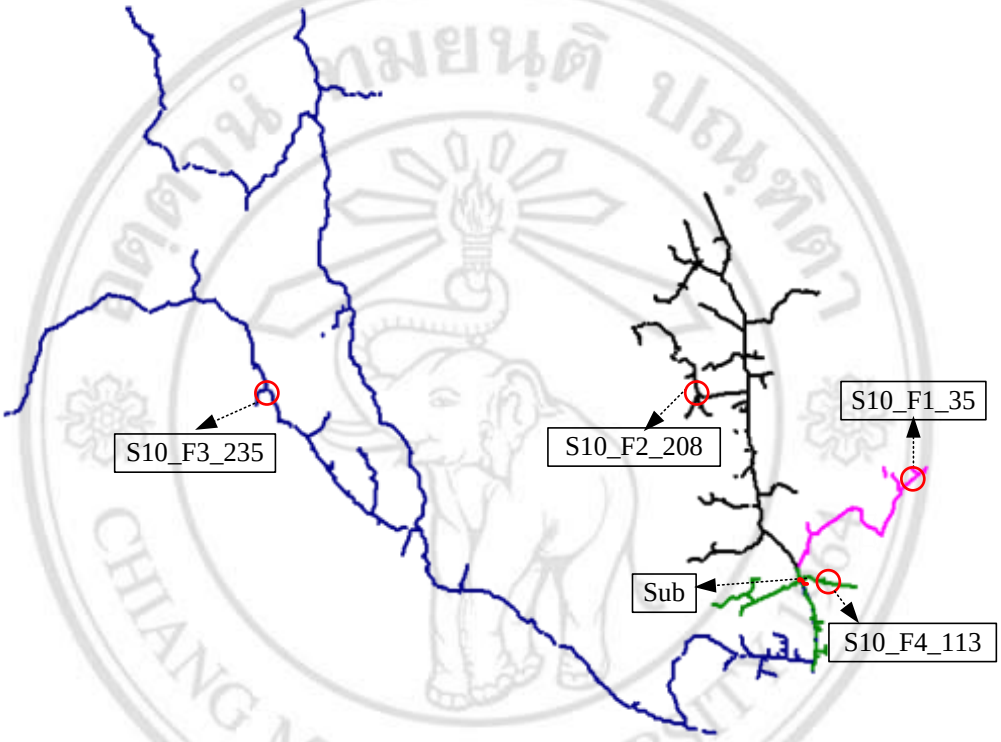

Figure 4.15 Location of installing LBS in Naxaythong substation

The table 4.27 showed the reliability indices before and after adding 5 sets of re-closer in Naxaythong substation. The reliability indices of SAIFI, SAIDI and CAIDI after adding re-closer were decreasing from 13.95 to 12.73 (1.22 time/customer/year), 466.22 to 386.47 (79.75 hour/customer/year) and 33.42 to 30.40 (3.03 hour/year), respectively

Table 4.27 Summary of reliability indices in Naxaythong substation

	Load kW	SAIFI (time/customer/year)	SAIDI (hour/customer/year)	CAIDI (hour/year)
Before	21,957	13.95	466.22	33.42
After	18,924.72	12.73	386.47	30.40
Change		**1.22**	**79.75**	**3.03**

4.6.1.3 Installing re-closer

1. Phontong substation

The re-closer 5 sets were installed in Phontong substation for enhancement, reliability indices as: S5_F1_45, S5_F2_62, S5_F3_138, S5_F4_85 and S5_F5_280 as shown in table 2.8 and Figure 4.16.

Table 4.28 Installing re-closer of feeders in Phontong substation

Feeders	Section Id
MSS 5.1	S5_F1_45
MSS 5.2	S5_F2_62
MSS 5.3	S5_F3_138
MSS 5.4	S5_F4_85
MSS 5.5	S5_F5_280

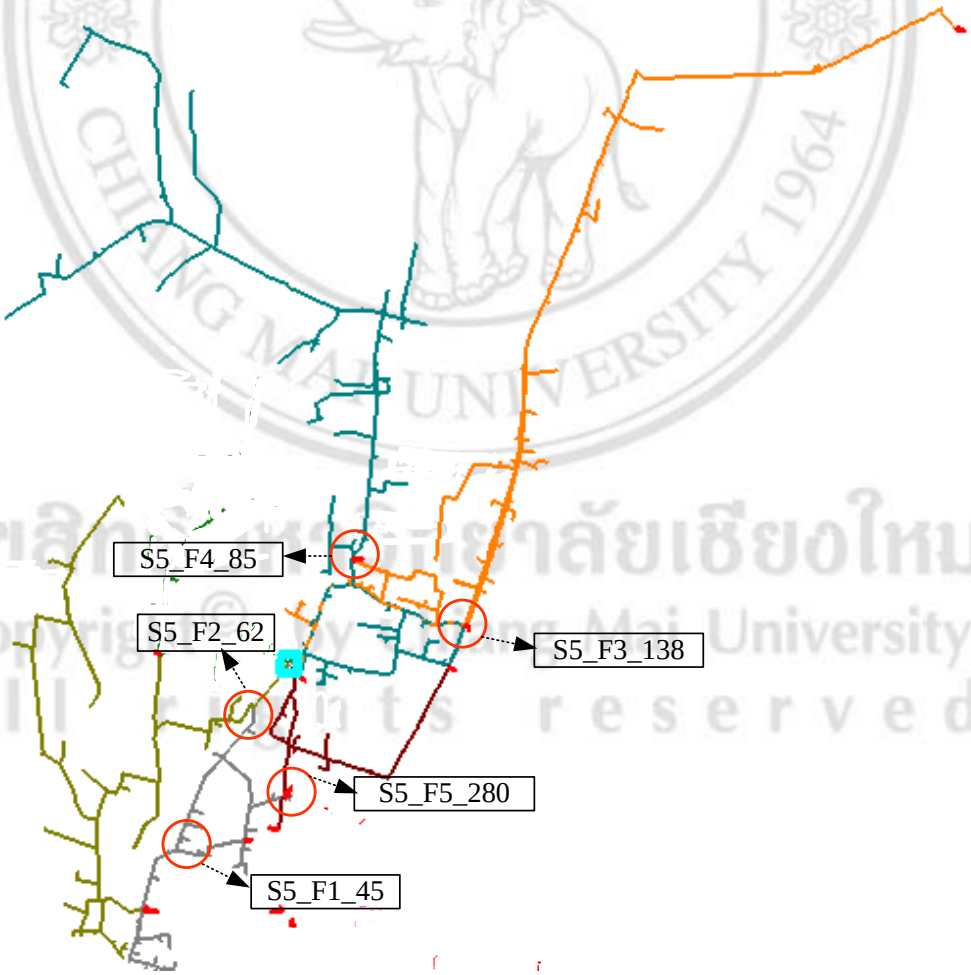

Figure 4.16 Location of installing re-closer of Phontong substation.

The table 4.29 showed the reliability indices before and after adding re-closer in Phontong substation. After that, adding 5 sets of re-closer the reliability indices in SAIFI, SAIDI and CAIDI were decreasing from 4.78 to 3.73 (1.05 time/customer/year), 24.63 to 14.74 (9.89 hour/customer/year) and 5.15 to 3.95 (1.2 hour/year), respectively.

Table 4.29: Summary of reliability indices of Phontong substation

	Load kW	SAIFI (time/customer/year)	SAIDI (hour/customer/year)	CAIDI (hour/year)
Before	45,936.40	4.78	24.63	5.15
After	45,454.06	3.73	14.74	3.95
Change		**1.05**	**9.89**	**1.2**

2. Thanaleng substation

The re-closer 5 sets were installed in Thanaleng substation for enhancement, reliability indices as: S6_F4_21, S6_F5_229, S6_F6_180 and S6_F7_224 as shown in table 4.30 and Figure 4.17.

Table 4.30 Installing re-closer of feeders in Thanaleng substation

Feeders	Section Id
MSS 6.4	S6_F4_21
MSS 6.5	S6_F5_229
MSS 6.6	S6_F6_180
MSS 6.7	S6_F7_224

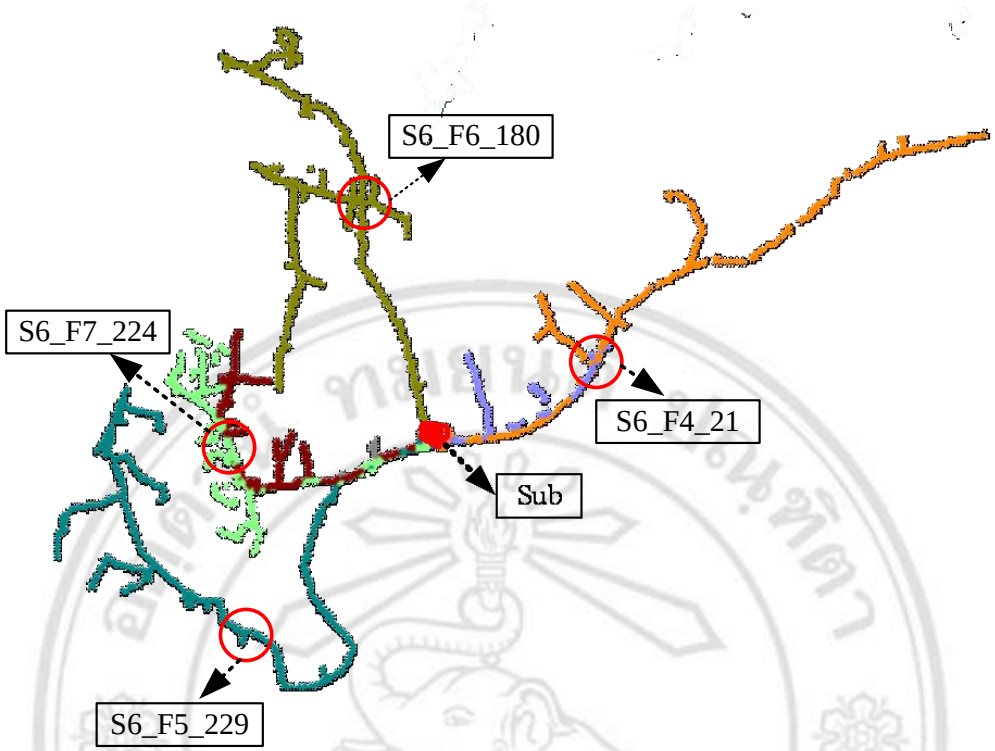

Figure 4.17 Location of installing re-closer of Thanaleng substation.

The table 4.31 showed the reliability indices before and after adding re-closer in Thanaleng substation. After that, adding 4 sets of re-closer the reliability indices in SAIFI, SAIDI and CAIDI were decreasing from 4.33 to 3.24 (1.09 time/customer/year), 160.57 to 113.18 (47.39 hour/customer/year) and 37.07 to 34.84 (2.18 hour/year), respectively.

Table 4.31: Summary of reliability indices of Thanaleng substation

	Load kW	SAIFI (time/customer/year)	SAIDI (hour/customer/year)	CAIDI (hour/year)
Before	121,694	4.33	160.57	37.07
After	114,654.62	3.24	113.18	34.89
Change		**1.09**	**47.39**	**2.18**

3. ThaNgon substation

The re-closer 3 sets were installed in Thanaleng substation for enhancement, reliability indices as: S8_F1_281, S8_F3_176 and S8_F4_16 as shown in table 4.32 and Figure 4.18.

Table 4.32 Installing re-closer of feeders in Thanaleng substation

Feeders	Section Id
MSS 8.1	S8_F1_281
MSS 8.3	S8_F3_176
MSS 8.4	S8_F4_16

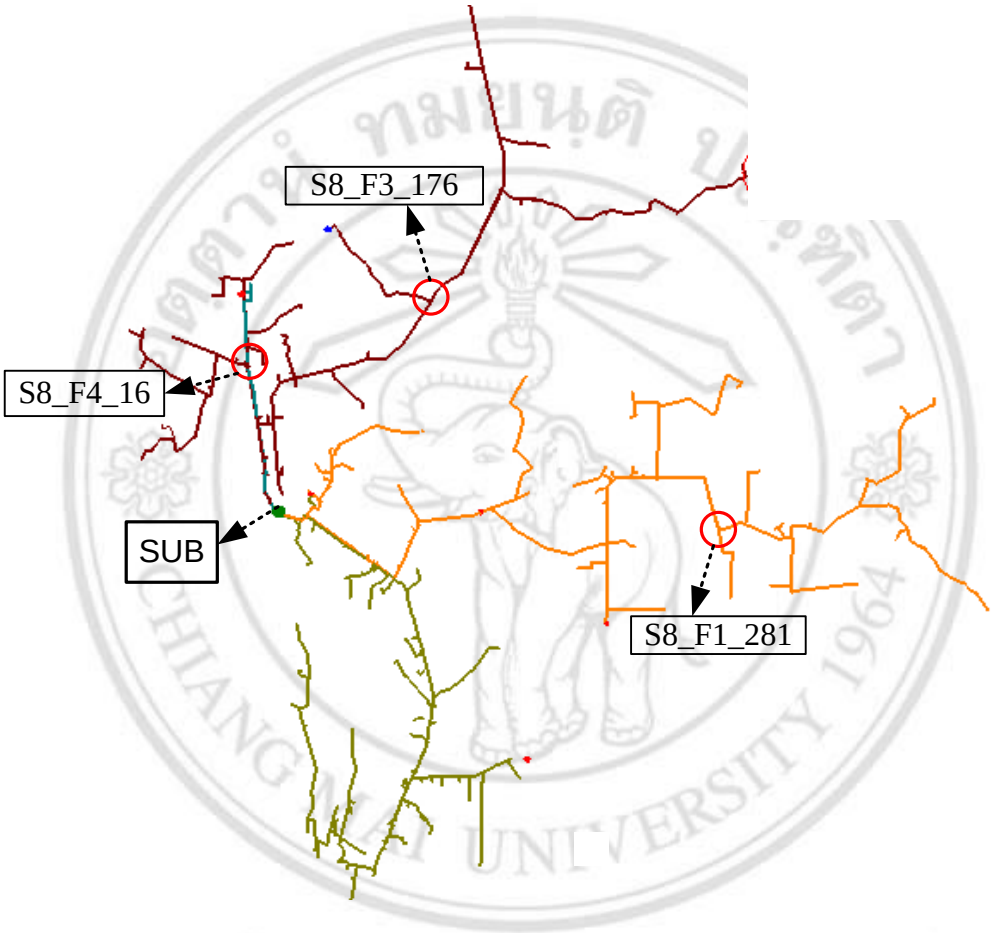

Figure 4.18 Location of installing, re-closer of ThaNgon substation.

The table 4.33 showed the reliability indices before and after adding re-closer in ThaNgon substation. After that, adding 3 sets of re-closer reliability indices in SAIFI, SAIDI and CAIDI were decreasing from 3.79 to 2.96 (0.83 time/customer/year), 74.51 to 50.12 (24.39 hour/customer/year) and 19.63 to 16.90 (2.73 hour/year), respectively.

Table 4.33: Summary of reliability indices of ThaNgon substation

	Load kW	SAIFI (time/customer/y)	SAIDI (hour/customer/year)	CAIDI (hour/year)
Before	19,260.70	3.79	74.51	19.63
After	16,362.94	2.96	50.12	16.90
Change		**0.83**	**24.39**	**2.73**

4. Khoksa-at substation

The re-closer 5 sets were installed in Khoksa-at substation for enhancement, reliability indices as: S9_F1_51, S9_F2_125, S9_F3_199, S9_F4_18 and S9_F6_100 as shown in table 4.34 and Figure 4.19.

Table 4.34 Installing re-closer of feeders in Khoksa-at substation

Feeders	Section Id
MSS 9.1	S9_F1_51
MSS 9.2	S9_F2_125
MSS 9.3	S9_F3_199
MSS 9.4	S9_F4_18
MSS 9.5	S9_F6_100

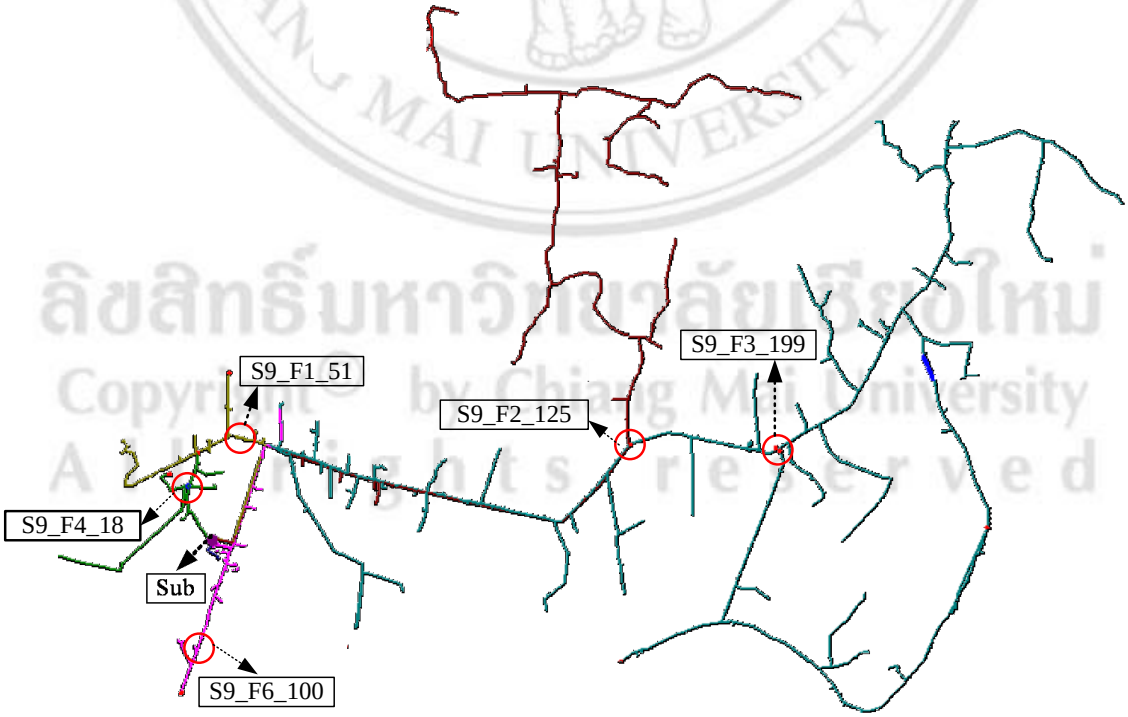

Figure 4.19 Location of installing, re-closer of Khoksa-at substation.

The table 4.35 showed the reliability indices before and after adding re-closer in Thanaleng substation. After that, adding 5 sets of re-closer the reliability indices in SAIFI, SAIDI and CAIDI were decreasing from 3.33 to 2.58 (0.75 time/customer/y), 58.79 to 41.25 (17.54 h/customer/y) and 17.64 to 15.95 (1.69 hour/year), respectively.

Table 4.35: Summary of reliability indices of Khoksa-at substation

	Load kW	SAIFI (time/customer/year)	SAIDI (hour/customer/year)	CAIDI (hour/year)
Before	46,719.9	3.33	58.79	17.64
After	39,962.33	2.58	41.25	15.95
Change		**0.75**	**17.54**	**1.69**

5. Naxaythong substation

The re-closer 4 sets were installed in Naxaythong substation for enhancement, reliability indices as: S10_F1_29, S10_F2_151, S10_F3_210 and S10_F4_113 as shown in table 4.36 and Figure 4.20.

Table 4.36 Installing re-closer of feeders in Naxaythong substation

Feeders	Section Id
MSS 10.1	S10_F1_29
MSS 10.2	S10_F2_151
MSS 10.3	S10_F3_210
MSS 10.4	S10_F4_113

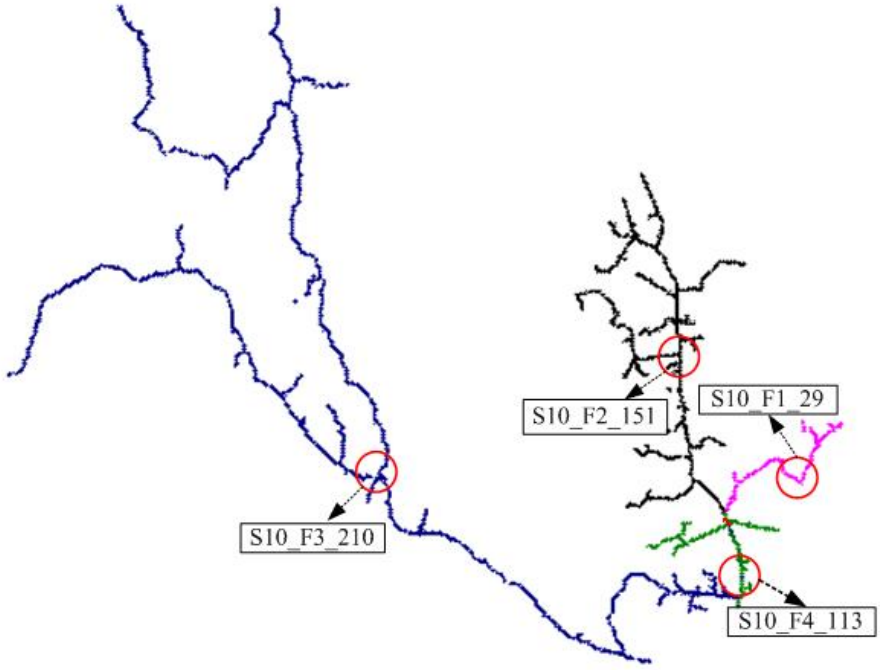

Figure 4.20 Location of installing, re-closer of Naxaythong substation.

The table 4.37 showed the reliability indices before and after adding re-closer in Thanaleng substation. After that, adding 4 sets of re-closer the reliability indices in SAIFI, SAIDI and CAIDI were decreasing from 13.95 to 10.44 (3.51 time/customer/year), 466.22 to 312.91 (153.31 hour/customer/year) and 33.42 to 29.97 (3.45 hour/year), respectively.

Table 4.37: Summary of reliability indices in Naxaythong substation

	Load kW	SAIFI (time/customer/year)	SAIDI (hour/customer/year)	CAIDI (hour/year)
Before	21,957	13.95	466.22	33.42
After	18,324.24	10.44	312.91	29.97
Change		**3.51**	**153.31**	**3.45**

4.7 Summarize of switching optimization of the distribution system in Vientiane capital

The distribution system efficiency is enhanced by improved reliability index with installation protection equipment modeling in appropriate point at outage areas such as: DS, LBS and re-closer wih various positions. The reduced numbers of interruption customer can be observed. Selection of appropriate positions in outage areas and have

more interruption customer before testing Installation equipment in 10 cases as shown in table 4-38. The frequency and interruption period can be reduced. The result consists of 10 cases which can be observed that the SAIFI(time/customer/year) and SAIDI (hour/customer/year) are decreasing respectively with the installation of DS 33 sets, LBS 21 sets and re-closer 21 sets.

Table 4.38 Summarize installation switches in the distribution system

	Name of substations	Name of feeders	Switching optimization				
			SAIFI (time/customer/year)	SAIDI (hour/customer/year)	DS sets	LBS sets	Re-closer sets
Case1	Phontong	1,2,3	5.67	633.75	6	3	3
Case2	Phontong	4,5	5.76	647.22	4	2	2
Case3	Thanaleng	5,7	5.73	628.92	2	2	2
Case4	Thanaleng	4	5.74	618.59	2	2	2
	Koksa-at	6					
Case5	ThaNgon	2,3,4	5.68	615.06	3	2	2
Case6	ThaNgon	1	5.72	621.71	2	2	2
	Koksa-at	1					
Case7	Koksa-at	1,4	5.79	640.93	4	2	2
Case8	Koksa-at	3	5.71	617.95	2	2	2
	Thanaleng	5					
Case9	Naxaythong	1,2	5.69	596.05	4	2	2
Case10	Naxaythong	3,4	5.70	595.87	4	2	2
Total			**5.72**	**621.57**	**33**	**21**	**21**

4.8 Analysis results

4.8.1 Improving of economic analysis in the cases

The cost of installing protected equipment to increase of reliability in the distribution system. From statistic in 2013, found that consumption still has more demand to react of power. The table 4.39 to 4.42 is a cost for installing protected equipment. Protected equipment (DS, LBS and re-closer) were installation in 10 cases allocated in 5 substation, the investment cost has least than saving cost.

Table 4.39 Summarize savings, cost of the DS

Name of substation	Disconnect Switch				
	Switch	Savings			Savings cost
	Investment	SAIFI	SAIDI	CAIDI	
	USD	(time/customer/year)	(hour/customer/y)	(hour/year)	USD
Phonethong	60,000	0.87	4.86	0.08	113,140.54
Thanaleng	18,000	0.84	33.89	0.70	13,300.55
Tha Ngon	30,000	0.34	17.19	3.01	75,125.24
Koksa-at	36,000	0.08	8.66	0.64	35,643.32
Naxaythong	48,000	2.48	85.92	0.24	89,398.31
Total	**192,000**	**4.64**	**150.53**	**4.69**	**326,607.97**

Table 4.40 Summarize savings, cost of LBS

Name of substation	Load Break Switch				
	Switch	Savings			Savings cost
	Investment	SAIFI	SAIDI	CAIDI	
	USD	(time/customer/year)	(hour/customer/year)	(hour/year)	USD
Phonethong	12,500	0.421	2.456	0.063	23,724
Thanaleng	7,500	0.415	20.079	1.200	1,713
Tha Ngon	7,500	0.357	20.404	3.870	5,119
Koksa-at	10,000	0.031	12.006	2.070	3,547
Naxaythong	10,000	1.237	79.748	3.020	19,019
Total	**47,500**	**2.462**	**134.693**	**10.223**	**53,122**

Table 4.41 Summarize savings, cost of re-closer

Name of substation	Re-closer				
	Switch	Savings			Savings cost
	Investment	SAIFI	SAIDI	CAIDI	
	USD	(time/customer/year)	(hour/customer/year)	(hour/year)	USD
Phonethong	18,760	1.05	9.89	1.2	43,575
Thanaleng	11,256	1.08	47.38	2.18	11,705
Tha Ngon	11,256	0.82	24.38	2.73	10,991
Koksa-at	15,008	0.45	17.54	1.69	15,151
Naxaythong	15,008	3.50	153.31	3.45	16,323
Total	**71,288**	**6.92**	**252.43**	**11.23**	**97,745**

Based on the results of the forecasted demand on technical analyses, estimated investment costs, reference data and assumptions; table 4.39 to 4.42 summarizes the results of financial analyses for installation protected equipment such as re-closer, DS and Load break switch. The results of detailed analyses are given in appendix B.

Table 4.42 Results of economic analysis of protective equipment

Name of Substations	Disconnect Switch			Load Break Switch			Re- closer		
	NPV	IRR	B/C Ratio	NPV	IRR	B/C Ratio	NPV	IRR	B/C Cost Ratio
	$x10^3$ USD	%	> 1	$x10^3$ USD	%	> 1	$x10^3$ USD	%	> 1
Phonethong	91.03	27.92%	21.59	17.48	30.02%	7.59	69.45	43.97%	26.15
Thanaleng	47.16	57.85%	6.74	40.38	76.16%	3.60	29.64	55.44%	7.96
Tha Ngon	94.19	39.32%	5.68	32.02	70.78%	7.62	31.68	57.83%	8.58
Koksa-at	51.59	34.55%	5.29	32.71	71.39%	7.91	46.64	60.07%	9.99
Naxaythong	120.73	40.28%	8.23	24.54	37.99%	18.17	42.45	56.91%	8.41
Total	**404.7**	**199.92%**	**47.53**	**147.13**	**286.34%**	**44.89**	**219.86**	**274.22%**	**61.09**

The table 4.42 were shown economic analysis of protective equipment in Thanaleng substation the IRR of DS and LBS were higher more than other substation. The re-closer was higher in Koksa-at substation.

4.8.2 Economic for protective equipment placement

The summation of economic analyses for switching optimization can be depicted in Table 4.43. The results with detailed analyses are considered as high profit. The disconnecting switch 33 sets, Load Beak Switch 21 sets and re-closer 21 sets are also installed. The investment cost of case 3 is the least cost than other cases with investment cost of 24,508 and saving cost at 101,343.61 USD. The DS costs 6,000 USD/set, LBS costs 2,500 USD/set and re-closer, costs 3,753 USD/set. Therefore, the investment cost for 10 cases of protecting equipment is 335,382 USD. This case can reduce the reliability indies such as: SAIFI = 1.09 (times/customer/year), SAIDI = 373.45 (hours/customer/year), CAIDI = 43.69 (hours/year) and savings cost is 835,971.64 USD.

Table 4.43 Results of economic analyses of switching optimization

	Name of substations	Name of feeders	Installation			Investment	Change			Saving Cost
			DS	LBS	Re-closer		SAIFI	SAIDI	CAIDI	
			Set	Set	Set	USD	(time/customer/year)	(hour/customer/year)	(hour/year)	USD
Case1	Phontong	1,2,3	6	3	3	54,756	0.16	1.25	1.25	40,121.89
Case 2	Phontong	4,5	4	2	2	36,506	0.07	11.73	0.72	72,872.80
Case 3	Thanaleng	5,7	2	2	2	24,508	0.10	30.03	3.28	101,343.61
Case 4	Thanaleng	4	2	2	2	24,510	0.09	40.36	5.20	101,420.81
	Koksa-at	6								
Case 5	ThaNgon	2,3,4	3	2	2	36,512	0.15	43.89	4.76	81,488.34
Case 6	ThaNgon	1	2	2	2	24,510	0.11	37.24	4.31	99,287.77
	Koksa-at	1								
Case 7	Koksa-at	1,4	4	2	2	36,516	0.04	18.02	2.27	80,241.63
Case 8	Koksa-at	3	2	2	2	24,510	0.11	41	4.89	100,131.08
	Thanaleng	5								
Case 9	Naxaythong	1,2	4	2	2	36,520	0.13	62.9	8.38	80,602.52
Case 10	Naxaythong	3,4	4	2	2	36,522	0.12	63.08	8.59	78,461.19
Total			**33**	**21**	**21**	**335,382**	**1.09**	**373.45**	**43.69**	**835,971.64**