CHAPTER 3

Methodology

The methodology for this research is applied Reliability Centered Maintenance (RCM), which has considered the severity level that may be incurred when the equipment cannot operate as its functions. These order the necessity of maintenance activity for the appropriate maintenance of each equipment.

This chapter introduces the techniques of RCM method to apply the RCM procedure for fitting the data of the Electricité du Laos (EDL). The RCM will be firstly selected the scope of the system by studying the operation and function of each equipment in the system. Then, it will be considered the failure mode that may be occurred on each equipment, including the impact that will be subsequent damage in each case. The failure mode of any event will be ordering the priority by studying the risk that is occurred in any failure mode of each equipment. The frequency and the subsequent damage of the failure mode must be known to order the priority of the equipment damage. These prioritize each failure mode causing the severe impact or not to the system. After that, the RCM will be considered the failure mode that is severely impacted the system by studying the type of maintenance activity, which will be selected the appropriate activity and frequency of maintenance for each event. Finally, the result of the process can be used as a routine of the maintenance plan. The maintenance activity based on the principle of RCM can be compared the old maintenance task to decrease or increase some activity, which can get the appropriate maintenance activity for the distribution system.

The Figure 3.1 has shown the process of RCM that is applied for electrical distribution system of Phontong substation, which is responsible to the EDL.

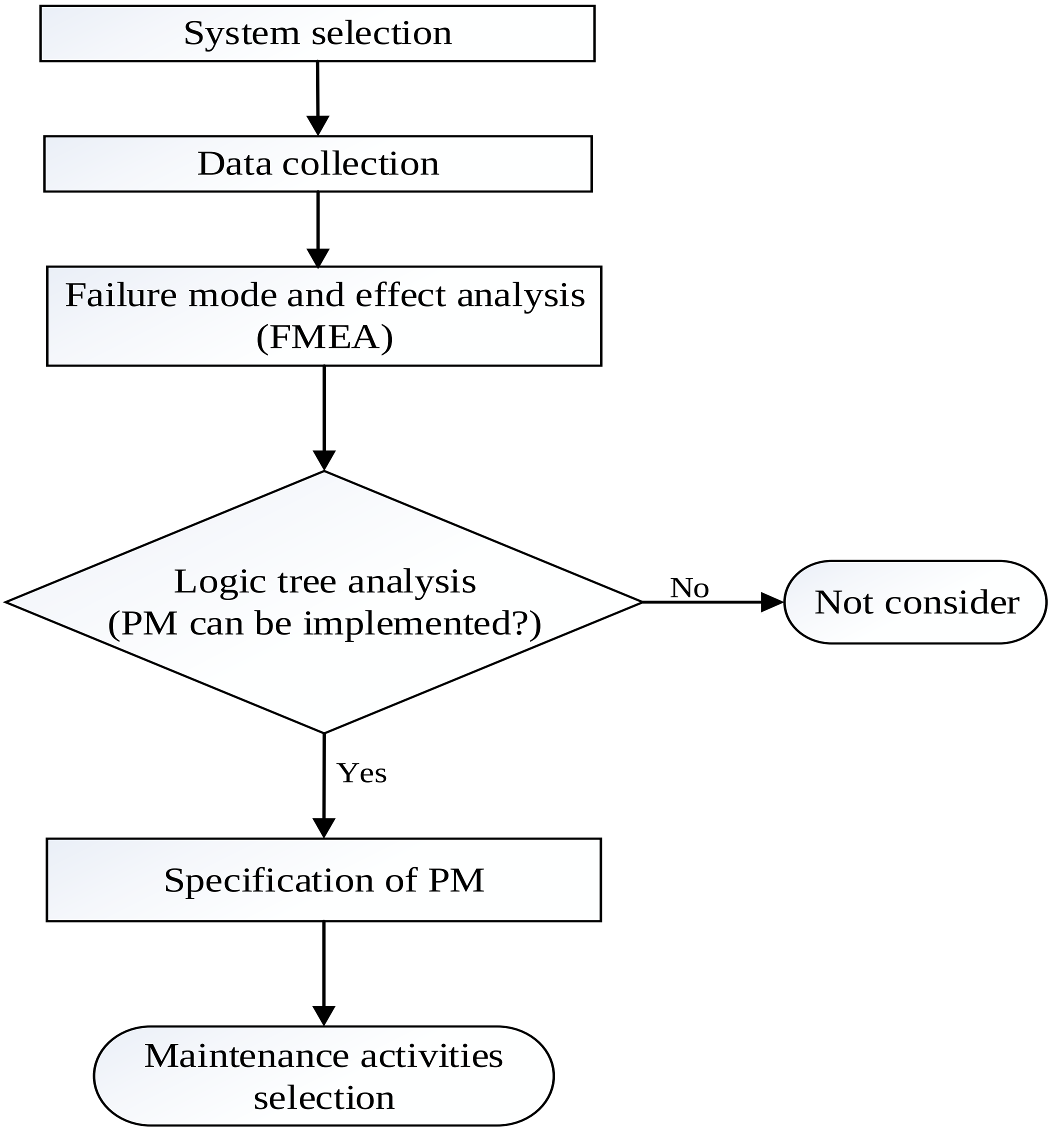

Figure 3.1 The process of Reliability Centered Maintenance

3.1. System selection and data collection

3.1.1. System selection

The system selection depends on the required maintenance planning and the detailed data of maintenance that needs the scope of maintenance planning. The system selection is also considered the detail of data in maintenance activities, which was recorded by EDL.

This case study has considered the existing distribution system of Phontong substation, which has the overall problem occurring in the system cause mostly down tree, animals, equipment, natural disaster and other event. The damage that is occurred in the system will be affected the customer directly. The failure rate of each feeder can be determined by using the power interruption data, which is recorded. For this study will be used the feeders that have the highest failure rate. The failure rate of each feeders are calculated by DIgSILENT PowerFactory V.15.1 software that has the procedure, which can be found in appendix and its result has been shown in the Table 3.1 and Figure 3.2

Table 3.1 The failure rate of Phontong substation feeders

Feeder	**SAIFI (Time/year)**	**SAIDI (H/year)**	**Interruption**	
			Outage (H/year)	**Outage (Time/year)**
MSS 5.1	1.38	0.07	0.05	3
MSS 5.2	4.61	8.08	1.75	10
MSS 5.3	4.11	11.99	2.92	7
MSS 5.4	0.43	0.01	0.02	1
MSS 5.5	5.84	54.48	9.33	23
MSS 5.6	4.96	8.59	1.73	11
MSS 5.7	3.53	2.35	0.67	12
MSS 5.8	7.01	29.79	4.25	30

Note: MSS is a code name used for distribution feeder of Phontong substation.

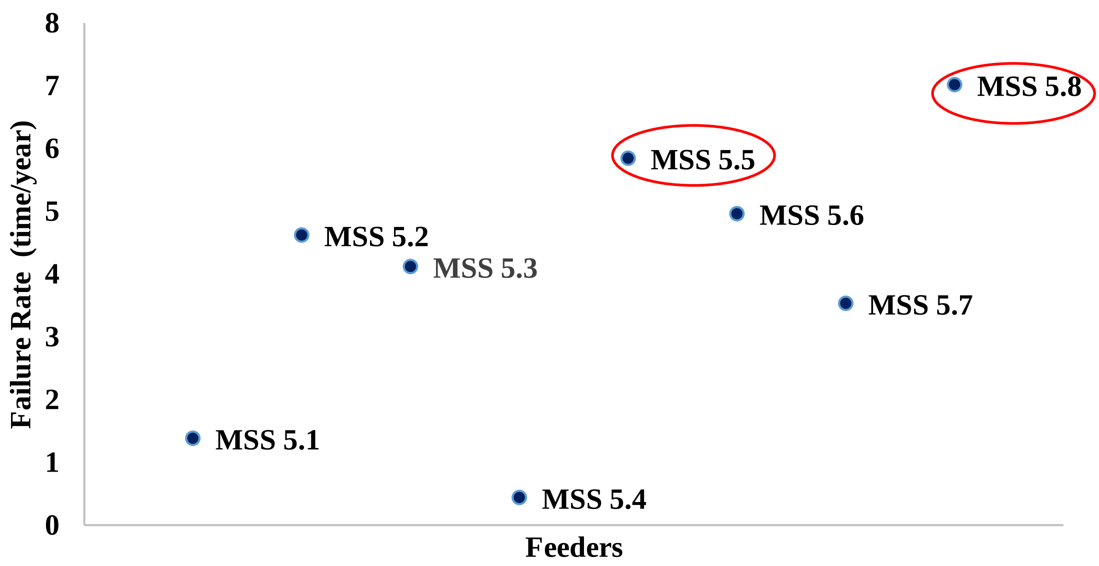

Figure 3.2. The power interruption of each feeders

Based on the result of failure rate calculation, this study will be used the feeders, which are MSS 5.5 and MSS 5.8 with the highest failure rates. The feeder MSS 5.5 and feeder MSS 5.8 have been selected as they both require the most maintenance.

3.1.2. Data collection

All of data collection has been started from the collection of maintenance activity data within the scope of the study. All of technical data will be supplied and collected from EDL and utility.

The important maintenance data used for RCM such as: the activity information on maintenance, the information cost on maintenance of the system. All of maintenance activities must be considered, including preventive maintenance, corrective maintenance and improvement maintenance.

3.2. Failure mode and effect analysis

FMEA is started to determine the failure causes and failure mode for any interruption, which will occurs within the equipment. After that, it will be defined the failure severity and failure frequency for each failure mode. Based on the failure severity and failure frequency, the FMEA is considered the relationship analysis between failure frequency and damage severity to be used for determining the critical impact of each event.

The relationship analysis between failure frequency and damage severity is applied to determine the critical impact for each interruption event. The RCM will be maintained the important equipment which supports the continuity of the power supply and it also determines the causes of individual interruptions. The interruption data, events frequency, and customer outage costs can be used and help find to know the levels of impact and severity of failure. The Figure 3.3 shows the process of critical impact determination for each interruption event.

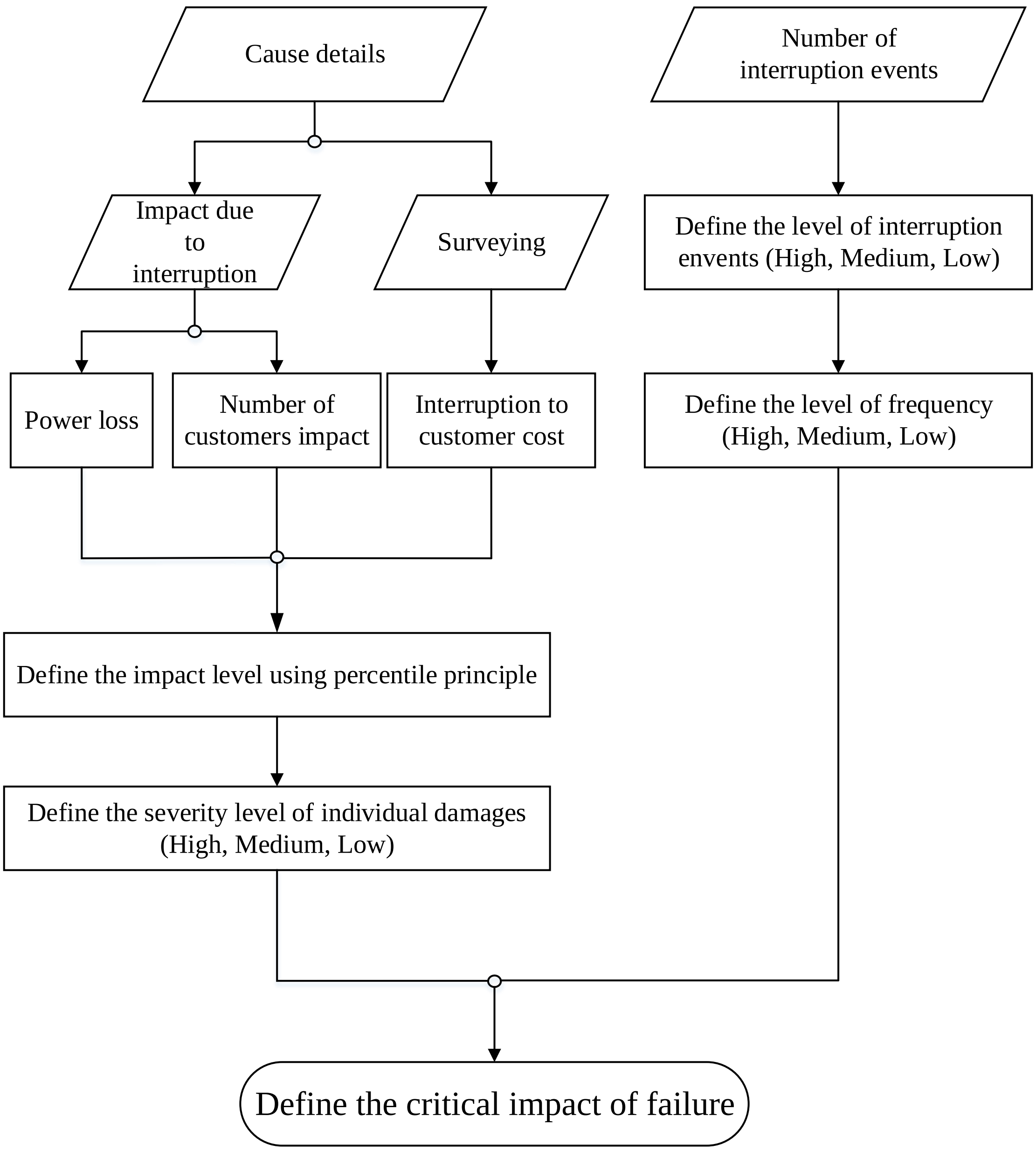

Figure 3.3 The process of critical impact determination

3.2.1. Cause and failure mode

The power interruption statistical data, including date of interruption, operation equipment, outage duration and interruption cause has been used. The example of cause and failure mode data, which is recorded by EDL as shown in Table 3.2.

Table 3.2 The example for data record of interruption event

Date	Feeder	Hardware	Failure mode		Cause
			Symptom	**Physical damage**	
6/Jan/2015	5.5	Conductor	Flash to ground		Down tree
11/Jan/2015	5.5	Conductor	Flash to ground		Lightning struck a tree
11/Jan/2015	5.8	CB	Trip (be able to re-operate)		Unknown
12/Feb/2015	5.5	Re-closer	Trip and re-close		Re-closer operation from bird at an insulator
24/Feb/2015	5.8	Re-closer	Trip and re-close		Re-closer operation from tree
5/Mar/2015	5.8	Insulator	Flash to ground		Lightning
8/Mar/2015	5.5	Drop out fuse	Burn	Crack	Damage to drop out fuse cutout
10/Mar/2015	5.5	Drop out fuse	Burn	Broken	Equipment fails from fuse housing
10/Mar/2015	5.8	DS	Flashover		Looseness
27/Mar/2015	5.5	DS		Dirt	Environment
28/Mar/2015	5.8	CB	Trip and re-operate		Equipment fails
7/Apr/2015	5.8	Re-closer	Trip and re-close		Re-closer operation from tree
7/Apr/2015	5.8	LA	Flashover, Burn		Equipment fails
7/Apr/2015	5.8	CB	Trip		Over load
7/Apr/2015	5.8	CB	Trip		Over load
10/Apr/2015	5.8	Conductor	Flash to ground		Tree branch touched the conductor
22/Apr/2015	5.8	Pole		Broken	Car crashed the pole
26/Apr/2015	5.5	Fuse of Tr	Burn	Broken	Equipment fails
26/Apr/2015	5.8	CB	Trip and re-operate		Equipment fails
28/Apr/2015	5.5	LA	Flashover		Lightning
28/Apr/2015	5.5	LA	Flashover		Lightning

Table 3.2 The example for data record of interruption event (continued)

Date	Feeder	Hardware	Failure mode		Cause
			Symptom	Physical damage	
28/Apr/2015	5.5	LA	Burn	Crack	Equipment fails because of lightning
28/Apr/2015	5.5	Insulator		Dirty	Environment
28/Apr/2015	5.5	Insulator+Conductor		Broken	Accident from crane truck
28/Apr/2015	5.8	CB	Trip and re-operate		Unknown
6/May/2015	5.8	Re-closer	Trip and re-close		Re-closer operation from tree
6/May/2015	5.8	Re-closer	Trip and lockout		Re-closer operated from tree to conductor
27/May/2015	5.8	CB	Trip and re-operate		Unknown
31/May/2015	5.5	CB	Trip and re-operate		Unknown
3/Jun/2015	5.5	CB	Trip and re-operate		Equipment fails
14/Jun/2015	5.8	Transformer	Burn	Crack of low voltage bushing	Cat climbs to transformer bushing
21/Jun/2015	5.8	Insulator		Contaminate, dirt	Environment
22/Jun/2015	5.8	Insulator		Contamination, dirty	Environment
22/Jun/2015	5.8	Conductor	Flash to ground		Tree branch falls down to the conductor
4/Jul/2015	5.8	Transformer	Burn	Crack of low voltage bushing	Snake climbs to the transformer
16/Jul/2015	5.8	Transformer		Dirt at bushing	Environment
30/Jul/2015	5.8	LA		Contamination, dirty	Environment
23/Aug/2015	5.5	DS	Arcing		Equipment fails
23/Aug/2015	5.5	Insulator		Contaminate, dirt	Environment
23/Aug/2015	5.5	DS		Contaminate, dirt	Environment
1/Sep/2015	5.5	Insulator		Contamination	Environment
8/Sep/2015	5.5	Insulator	Flashover	Crack	Equipment fails

Table 3.2 The example for data record of interruption event (continued)

Date	Feeder	Hardware	Failure mode		Cause
			Symptom	**Physical damage**	
10/Sep/2015	5.8	Transformer	Flashover		Bird at transformer bushing
29/Sep/2015	5.8	Conductor	Flashover		Flash from conductor to cross beam because of bird at insulator
5/Oct/2015	5.8	Re-closer	Trip and re-close		Re-closer operated from tree
6/Oct/2015	5.8	Re-closer	Trip and re-close		Re-closer operated from tree
18/Oct/2015	5.5	Pole		Broken	Truck crashed the pole
18/Oct/2015	5.8	Conductor		Broken	Accident from truck crane
18/Oct/2015	5.5	CB	Trip and re-operate		Equipment fails
3/Nov/2015	5.5	Re-closer	Trip and re-close		Re-closer operated from snake climbs up the pole
16/Nov/2015	5.8	Drop out fuse	Flashover	Broken	Damage to drop out fuse cutout from cat at the transformer
16/Nov/2015	5.8	CB	Trip and re-operate		Unknown

3.2.2. Failure severity determination

FMEA has defined the failure severity by considering the impact or severity of interruption event, which is occurred in the system. The failure severity is considered by three condition as below:

1) Electrical power losses due to the interruption
2) Number of customer impact due to the interruption
3) Customer outage cost due to the interruption

The Table 3.3 shows the example for data record of power losses and number of customer impact due to the power interruption recorded by EDL

Table 3.3 The example for data of power losses and customer impact number

Date	Feeder	kVA	Duration (Mn)	Customer
6/Jan/2015	5.5	280	1	302
11/Jan/2015	5.5	1794	1	1294
11/Jan/2015	5.8	4974	1	14832
12/Feb/2015	5.5	1794	1	1294
24/Feb/2015	5.8	1988	1	2869
5/Mar/2015	5.8	732	1	998
8/Mar/2015	5.5	328	15	475
10/Mar/2015	5.5	1776	28	1560
10/Mar/2015	5.8	5032.8	3	11699
27/Mar/2015	5.5	1215	1	1745
28/Mar/2015	5.8	3979.2	1	14832
7/Apr/2015	5.8	1846	1	2869
7/Apr/2015	5.8	2636	21	2469
7/Apr/2015	5.8	3979.2	1	14832
7/Apr/2015	5.8	2984.4	1	14832
10/Apr/2015	5.8	1647.5	2	2469
22/Apr/2015	5.8	376	117	522
26/Apr/2015	5.5	1776	25	1560
26/Apr/2015	5.8	2984.4	1	14832
28/Apr/2015	5.5	1215	1	261
28/Apr/2015	5.5	1316.25	1	261
28/Apr/2015	5.5	1620	33	261
28/Apr/2015	5.5	3920	120	14776
28/Apr/2015	5.8	3979.2	1	14832
6/May/2015	5.8	2516.4	10	11046
27/May/2015	5.8	4576.08	1	14832
31/May/2015	5.5	5600	1	14776

Table 3.3 The example for data of power losses and customer impact number (continued)

Date	Feeder	kVA	Duration (Mn)	Customer
3/Jun/2015	5.5	5600	1	14776
14/Jun/2015	5.8	4971	25	4441
21/Jun/2015	5.8	2516.4	1	11699
22/Jun/2015	5.8	2136.75	1	2869
4/Jul/2015	5.8	3355.2	1	11699
4/Jun/2015	5.8	5661.9	22	11699
16/Jul/2015	5.8	3382.32	1	14832
30/Jul/2015	5.8	3728.25	1	3788
23/Aug/2015	5.5	1620	3	1745
23/Aug/2015	5.5	1656	1	1294
23/Aug/2015	5.5	1113.75	1	1745
1/Sep/2015	5.5	1380	1	1294
8/Sep/2015	5.5	3676	17	2817
10/Sep/2015	5.8	2684.16	1	11699
29/Sep/2015	5.8	4971	5	3788
5/Oct/2015	5.8	2180.88	1	1294
6/Oct/2015	5.8	2180.88	1	11699
18/Oct/2015	5.5	389.5	20	11699
18/Oct/2015	5.8	5032.8	15	4441
31/Oct/2015	5.5	4690	1	14776
3/Nov/2015	5.5	2920	2	3756
16/Dec/2015	5.8	4888.15	15	4441
16/Dec/2015	5.8	2586.48	1	14832

For the customer outage due to the power interruption will be estimated by surveying and the interview of the customer on site when the interruption occurred. The customer outage data is classified by the interruption period of each type of customer as shown in Table 3.4 below:

Table 3.4 The customer outage cost of different types of customers

Customer type	Customer outage cost (USD/kWh)					
	< 1Mn	<1-30Mn	<30-60Mn	<60-120Mn	<120-240Mn	<240-480Mn
Residential	-	0.1453	0.2462	0.5395	1.1290	2.2863
Entertainment business	-	0.3109	0.8696	0.9080	4.6567	5.6514
Industrial	-	3.9039	9.8656	2.6243	17.5169	35.0514
Government	-	0.3147	0.5634	0.8377	1.1282	1.4284
Irrigation	-	0.8352	1.4889	2.6026	5.4388	10.2006
Education-sport business	-	0.0188	0.0533	0.1138	0.2300	0.4455
Other	-	0.3178	0.5671	0.8165	1.1379	1.4429

Based on the result of customer outage surveying when the interruption occurred, the customer outage cost of the feeder can be found in the Table 3.5 below:

Table 3.5 The customer outage cost of the feeders

Feeder	Customer	Duration (h)	Residential (USD)	Entertainment business (USD)	Industrial (USD)	Government (USD)	Irrigation (USD)	Education sport business (USD)	Other (USD)	Total outage cost (USD)
5.5	475	0.25	36.90	12.55	12.10	7.23	0.00	5.02	0.00	58.88
5.5	1560	0.47	380.42	141.72	0.00	149.18	0.00	0.00	74.59	169.97
5.5	1745	0.42	339.66	126.54	0.00	133.20	0.00	0.00	66.60	151.76
5.5	261	0.55	400.95	104.25	16.04	72.17	0.00	128.30	80.19	440.57
5.5	14776	2.00	3528.00	1028.06	1155.77	620.22	0.00	546.84	156.64	6579.63
5.5	1745	0.05	36.45	21.87	0.00	10.94	0.00	0.00	3.65	16.69
5.5	2817	0.28	421.82	131.23	140.61	131.23	0.00	84.36	28.12	702.80
5.5	11699	0.33	58.43	19.86	19.16	11.45	0.00	7.95	0.00	93.23
5.5	3756	0.03	35.92	19.27	13.14	9.64	0.00	6.13	3.50	66.77
5.8	11699	0.05	37.11	10.75	12.09	6.49	0.00	5.72	1.64	58.60
5.8	2469	0.35	335.66	82.05	96.97	134.27	0.00	67.13	29.84	505.82
5.8	2469	0.03	299.70	73.26	86.58	119.88	0.00	59.94	26.64	451.63
5.8	522	1.95	449.06	88.21	0.00	144.34	0.00	88.21	32.08	479.51
5.8	11046	0.17	3175.20	1481.76	564.48	1199.52	0.00	635.04	0.00	3514.96
5.8	4441	0.42	32.81	15.31	5.83	12.39	0.00	6.56	0.00	36.32
5.8	11699	0.37	421.82	196.85	74.99	159.35	0.00	84.36	0.00	466.96
5.8	3788	0.08	52.58	24.54	9.35	19.86	0.00	10.52	0.00	58.21
5.8	4441	0.25	39.42	18.40	7.01	14.89	0.00	7.88	0.00	43.64
5.8	4441	0.25	39.42	18.40	7.01	14.89	0.00	7.88	0.00	43.64

According to the data record of the power loss, the number of the customers and customer outage cost caused the power interruption. These data will be used to prioritize by using the principle of percentile for classifying the level of impact such as high, medium and low for each interruption event.

Typically, the classification of impact level will be considered any failure mode has the impact that is less than the position of percentile 25 will be low level (L), any failure mode has the impact that is in the range from 25 to 75 of percentile position will be medium level (M), because this failure has always occurred. Additionally, any failure mode has the impact that is more than 75 of percentile position will be leveled the high level (H). Because this failure mode is an unusual event, which can be affected to the customers as shown in Figure 3.4 below:

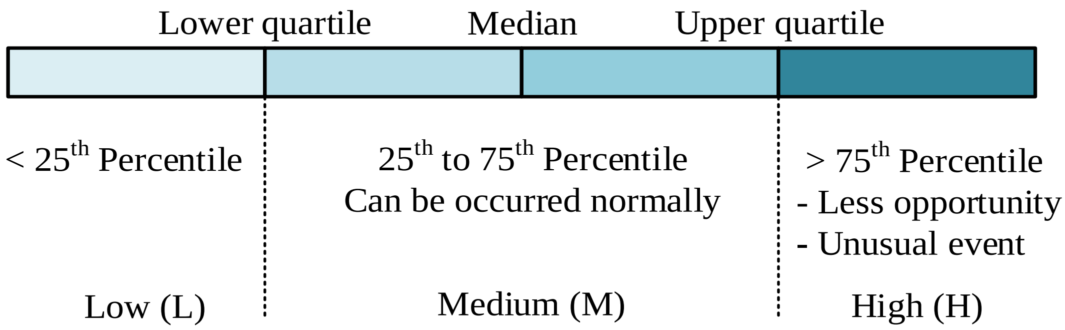

Figure 3.4 The impact level of interruption

After calculating the three impact level. the next step has defined the sum of each impact level by focusing on the same impact, including power loss impact, the number of customer impact and customer outage cost due to the power interruption. These define the score for each impact level as following:

- High level is equal 3 points
- Medium level is equal 2 points
- Low level is equal 1 point

Based on the sum of impact score, the new impact level can be defined as following:

- The sum of score range (1 to 3): Low level (L)
- The sum of score range (4 to 6): Medium level (M)
- The sum of score range (7 to 9): High level (H)

The data of causes detail will be used to prioritize the impact level for the number of customer impact due to the interruption, electrical power losses due to the interruption and also customer outage cost due to the interruption as shown in Table 3.6 to Table 3.8.

Table 3.6 The number of customer impact level due to the interruption

Feeder	Hardware	Action	Total customer	Cumulative Frequency	Level
MSS5.5	LA	Flashover	261	261	L
MSS5.5	LA	Flashover	261	522	L
MSS5.5	LA	Burn	261	783	L
MSS5.5	Insulator	Flashover	261	1044	L
MSS5.5	Conductor	Down tree	302	302	L
MSS5.5	Drop out fuse	Burn	475	777	L

Table 3.6 The number of customer impact level due to the interruption (continued)

Feeder	Hardware	Action	Total customer	Cumulative Frequency	Level
MSS5.8	Pole	Accident	522	1299	L
MSS5.8	Insulator	Flashover	998	2297	L
MSS5.5	Conductor	Down tree	1294	3591	L
MSS5.5	Re-closer	Animal	1294	4885	L
MSS5.5	Insulator	Flashover	1294	6179	L
MSS5.5	Insulator	Flashover	1294	7473	L
MSS5.5	Drop out fuse	Break	1560	9033	L
MSS5.5	Fuse of Tr	Break	1560	10593	L
MSS5.5	DS	Other	1745	12338	L
MSS5.5	DS	Other	1745	14083	L
MSS5.5	DS	Other	1745	15828	L
MSS5.8	LA	Flashover	2469	18297	L
MSS5.8	Conductor	Rain-Flashover	2469	20766	L
MSS5.5	Insulator	Crash	2817	23583	L
MSS5.8	Re-closer	Tree	2869	26452	L
MSS5.8	Re-closer	Down tree	2869	29321	L
MSS5.8	Insulator	Flashover	2869	32190	L
MSS5.5	Re-closer	Animal (snack at pole)	3756	35946	L
MSS5.8	LA	Flashover	3788	39734	L
MSS5.8	Conductor	Animal (bird at insulator)	3788	43522	L
MSS5.8	Transformer	Animal (cat)	4441	47963	L
MSS5.8	Conductor	Break-Accident	4441	52404	L
MSS5.8	Drop out fuse	Animal (cat)	4441	56845	L
MSS5.8	Re-closer	Tree	11046	67891	L
MSS5.8	Re-closer	Tree	11046	78937	L
MSS5.8	DS	Arcing	11699	90636	L
MSS5.8	Insulator	Flashover	11699	102335	M
MSS5.8	Conductor	Span (under)	11699	114034	M
MSS5.8	Transformer	Animal (snack)_PTT	11699	125733	M
MSS5.8	Transformer	Animal (bird at bushing)	11699	137432	M
MSS5.8	Re-closer	Down tree	11699	149131	M
MSS5.8	Re-closer	Down tree	11699	160830	M
MSS5.5	Pole	Accident	11699	172529	M
MSS5.5	Insulator+Conductor	Crash-Break	14776	187305	M
MSS5.5	CB	Other	14776	202081	M
MSS5.5	CB	Other	14776	216857	M
MSS5.5	CB	Other	14776	231633	M
MSS5.8	CB	Other	14832	246465	M

Table 3.6 The number of customer impact level due to the interruption (continued)

Feeder	Hardware	Action	Total customer	Cumulative Frequency	Level
MSS5.8	CB	Other	14832	261297	M
MSS5.8	CB	Trip (Overload)	14832	276129	H
MSS5.8	CB	Trip (Overload)	14832	290961	H
MSS5.8	CB	Trip (Overload)	14832	305793	H
MSS5.8	CB	Other	14832	320625	H
MSS5.8	CB	Other	14832	335457	H
MSS5.8	Transformer	Other	14832	350289	H
MSS5.8	CB	Other	14832	365121	H

Table 3.7 The power loss impact level due to the interruption

Feeder	Hardware	Action	kWh	Cumulative Frequency	Level
MSS5.5	Conductor	Down tree	4.20	4.20	L
MSS5.8	Insulator	Flashover	10.98	15.18	L
MSS5.5	DS	Other	16.71	31.89	L
MSS5.5	DS	Other	18.23	50.11	L
MSS5.5	LA	Flashover	18.23	18.23	L
MSS5.5	LA	Flashover	19.74	37.97	L
MSS5.5	Insulator	Flashover	20.70	58.67	L
MSS5.5	Insulator	Flashover	24.30	82.97	L
MSS5.5	Insulator	Flashover	24.84	107.81	L
MSS5.5	Conductor	Down tree	26.91	134.72	L
MSS5.5	Re-closer	Animal	26.91	161.63	L
MSS5.8	Re-closer	Down tree	27.69	189.32	L
MSS5.8	Re-closer	Tree	29.82	219.14	L
MSS5.8	Insulator	Flashover	32.05	251.19	L
MSS5.8	Re-closer	Down tree	32.71	283.90	L
MSS5.8	Re-closer	Down tree	32.71	316.62	L
MSS5.8	Re-closer	Tree	37.75	354.36	L
MSS5.8	Insulator	Flashover	37.75	392.11	L
MSS5.8	CB	Other	38.80	430.91	L
MSS5.8	Transformer	Animal (bird at bushing)	40.26	471.17	L
MSS5.8	CB	Trip (Overload)	44.77	515.93	L
MSS5.8	CB	Trip (Overload)	44.77	560.70	L
MSS5.8	Conductor	Rain-Flashover	49.43	610.13	L
MSS5.8	Conductor	Span (under)	50.33	660.45	L
MSS5.8	Transformer	Other	50.73	711.19	L
MSS5.8	LA	Flashover	55.92	767.11	L

Table 3.7 The power losses impact level due to the interruption (continued)

Feeder	Hardware	Action	kWh	Cumulative Frequency	Level
MSS5.8	CB	Other	59.69	826.80	L
MSS5.8	CB	Trip (Overload)	59.69	886.49	L
MSS5.8	CB	Other	59.69	946.18	L
MSS5.8	CB	Other	68.64	1014.82	L
MSS5.5	CB	Other	70.35	1085.17	L
MSS5.5	DS	Other	72.90	1158.07	L
MSS5.5	Drop out fuse	Burn	73.80	1231.87	L
MSS5.8	CB	Other	74.61	1306.48	L
MSS5.5	CB	Other	84.00	1390.48	L
MSS5.5	CB	Other	84.00	1474.48	L
MSS5.5	Re-closer	Animal (snack at pole)	87.60	1562.08	L
MSS5.5	Pole	Accident	116.85	1678.93	L
MSS5.8	DS	Arcing	226.48	1905.40	L
MSS5.8	Conductor	Animal (bird at insulator)	372.83	2278.23	L
MSS5.8	Re-closer	Tree	377.46	2655.69	L
MSS5.8	Pole	Accident	659.88	3315.57	L
MSS5.5	Fuse of Tr	Break	666.00	3981.57	L
MSS5.5	Drop out fuse	Break	745.92	4727.49	L
MSS5.5	LA	Burn	801.90	5529.39	L
MSS5.8	LA	Flashover	830.34	6359.73	L
MSS5.5	Insulator	Crash	937.38	7297.11	L
MSS5.8	Drop out fuse	Animal (cat)	1099.83	8396.94	L
MSS5.8	Conductor	Break-Accident	1132.38	9529.32	M
MSS5.8	Transformer	Animal (cat)	1864.13	11393.45	M
MSS5.8	Transformer	Animal (snack)_PTT	1868.43	13261.87	M
MSS5.5	Insulator+Conductor	Crash-Break	23755.20	37017.07	H

Table 3.8 The customer outage cost impact level due to the interruption

Feeder	Hardware	Action	USD	Cumulative Frequency	Level
MSS5.5	Conductor	Down tree	0	0.00	L
MSS5.5	Conductor	Down tree	0	0.00	L
MSS5.8	CB	Other	0	0.00	L
MSS5.5	Re-closer	Animal	0	0.00	L
MSS5.8	Re-closer	Tree	0	0.00	L
MSS5.8	Insulator	Flashover	0	0.00	L
MSS5.5	DS	Other	0	0.00	L
MSS5.8	CB	Other	0	0.00	L
MSS5.8	Re-closer	Down tree	0	0.00	L

Table 3.8 The customer outage cost impact level due to the interruption (continued)

Feeder	Hardware	Action	USD	Cumulative Frequency	Level
MSS5.8	CB	Trip (Overload)	0	0.00	L
MSS5.8	CB	Trip (Overload)	0	0.00	L
MSS5.8	CB	Trip (Overload)	0	0.00	L
MSS5.5	LA	Flashover	0	0.00	L
MSS5.5	LA	Flashover	0	0.00	L
MSS5.5	Insulator	Flashover	0	0.00	L
MSS5.8	CB	Other	0	0.00	L
MSS5.8	Re-closer	Tree	0	0.00	L
MSS5.8	CB	Other	0	0.00	L
MSS5.5	CB	Other	0	0.00	L
MSS5.5	CB	Other	0	0.00	L
MSS5.8	Insulator	Flashover	0	0.00	L
MSS5.8	Insulator	Flashover	0	0.00	L
MSS5.8	Conductor	Span (under)	0	0.00	L
MSS5.8	Transformer	Other	0	0.00	L
MSS5.8	LA	Flashover	0	0.00	L
MSS5.5	Insulator	Flashover	0	0.00	L
MSS5.5	DS	Other	0	0.00	L
MSS5.5	Insulator	Flashover	0	0.00	L
MSS5.8	Transformer	Animal (bird at bushing)	0	0.00	L
MSS5.8	Re-closer	Down tree	0	0.00	L
MSS5.8	Re-closer	Down tree	0	0.00	L
MSS5.5	CB	Other	0	0.00	L
MSS5.8	CB	Other	0	0.00	L
MSS5.5	DS	Other	16.69	16.69	L
MSS5.8	Transformer	Animal (cat)	36.32	53.01	L
MSS5.8	Conductor	Break-Accident	43.64	96.65	L
MSS5.8	Drop out fuse	Animal (cat)	43.64	140.29	L
MSS5.8	Conductor	Animal (bird at insulator)	58.21	198.50	L
MSS5.8	DS	Arcing	58.6	257.10	L
MSS5.5	Drop out fuse	Burn	58.88	315.98	L
MSS5.5	Re-closer	Animal (snack at pole)	66.77	382.75	L
MSS5.5	Pole	Accident	93.23	475.98	L
MSS5.5	Fuse of Tr	Break	151.76	627.74	L
MSS5.5	Drop out fuse	Break	169.97	797.71	L
MSS5.5	LA	Burn	440.57	1238.28	L
MSS5.8	Transformer	Animal (snack)_PTT	446.96	1685.24	L
MSS5.8	Conductor	Rain-Flashover	451.63	2136.87	L

Table 3.8 The customer outage cost impact level due to the interruption (continued)

Feeder	Hardware	Action	USD	Cumulative Frequency	Level
MSS5.8	Pole	Accident	479.51	2616.38	L
MSS5.8	LA	Flashover	505.82	3122.20	L
MSS5.5	Insulator	Crash	702.8	3825.00	M
MSS5.8	Re-closer	Tree	3514.96	7339.96	M
MSS5.5	Insulator+Conductor	Crash-Break	6579.63	13919.59	H

3.2.3. Failure frequency

The failure frequency determination is an important condition that will be used to find the critical impact of each interruption event. For example, the impact of failure is very high or severe, but it has a less opportunity occurred over the lifetime of the operation. In this case, it will be considered a failure that is less severe than the frequent interruption event. Consequently, the frequency of each failure must be defined to know the opportunity risk, which can be occurred and be damaged to the equipment or system. These prioritize the level of failure frequency by using the principle of percentile. The example of data record for failure frequency of each interruption event shown in the Table 3.9 below:

Table 3.9 The example of data record for failure frequency

Hardware	Number of event	Cause
Conductor	4	Flash to ground, Tree
	2	Broken, accident
CB	5	Unknown
	3	Equipment fails
	3	Overload
Re-closer	2	Re-closer operation from animal
	5	Re-closer operation from tree
Pole	2	Broken, accident
LA	2	Flashover, equipment
	2	Flashover, lightning
Fuse of transformer	1	broken, equipment
Transformer	3	Equipment fails form animal
	1	Environment
Insulator	1	Lightning
	5	Flashover, environment
	1	Accident
	1	Equipment fails

Table 3.9 The example of data record for failure frequency (continued)

Hardware	Number of event	Cause
DOF	2	Equipment fails
	1	Equipment fails from animal
DS	4	Equipment fails
	1	looseness

Based on the data record of failure frequency, the impact level of failure frequency can be found in the Table 3.10.

Table 3.10 The failure frequency impact level

Feeder	Hardware	Action	Failure frequency level
MSS5.5	Conductor	Down tree	M
MSS5.5	Conductor	Down tree	M
MSS5.8	CB	Other	H
MSS5.5	Re-closer	Animal	L
MSS5.8	Re-closer	Tree	H
MSS5.8	Insulator	Flashover	L
MSS5.5	Drop out fuse	Burn	M
MSS5.5	Drop out fuse	Break	M
MSS5.8	DS	Arcing	L
MSS5.5	DS	Other	M
MSS5.8	CB	Other	M
MSS5.8	Re-closer	Down tree	H
MSS5.8	LA	Flashover	M
MSS5.8	CB	Trip (Overload)	M
MSS5.8	CB	Trip (Overload)	M
MSS5.8	Conductor	Rain-Flashover	M
MSS5.8	Pole	Accident	M
MSS5.5	Fuse of Tr	Break	L
MSS5.8	CB	Trip (Overload)	M
MSS5.5	LA	Flashover	M
MSS5.5	LA	Flashover	M
MSS5.5	LA	Burn	M
MSS5.5	Insulator	Flashover	H
MSS5.5	Insulator+Conductor	Crash-Break	L
MSS5.8	CB	Other	H
MSS5.8	Re-closer	Tree	H
MSS5.8	Re-closer	Tree	H
MSS5.8	CB	Other	H
MSS5.5	CB	Other	H

Table 3.10 The failure frequency impact level (continued)

Feeder	Hardware	Action	Failure frequency level
MSS5.5	CB	Other	M
MSS5.8	Transformer	Animal (cat)	M
MSS5.8	Insulator	Flashover	H
MSS5.8	Insulator	Flashover	H
MSS5.8	Conductor	Span (under)	M
MSS5.8	Transformer	Animal (snack)_PTT	M
MSS5.8	Transformer	Other	L
MSS5.8	LA	Flashover	M
MSS5.5	DS	Other	M
MSS5.5	Insulator	Flashover	H
MSS5.5	DS	Other	M
MSS5.5	Insulator	Flashover	H
MSS5.5	Insulator	Crash	L
MSS5.8	Transformer	Animal (bird at bushing)	M
MSS5.8	Conductor	Animal (bird at insulator)	H
MSS5.8	Re-closer	Down tree	H
MSS5.8	Re-closer	Down tree	H
MSS5.5	Pole	Accident	M
MSS5.8	Conductor	Break-Accident	L
MSS5.5	CB	Other	M
MSS5.5	Re-closer	Animal (snack at pole)	L
MSS5.8	Drop out fuse	Animal (cat)	L
MSS5.8	CB	Other	H

3.2.4. Critical impact of each failure mode

The result of calculation for the impact level of each event and failure frequency of each event will be applied to consider the critical impact for each interruption event. It can help to know the severity that has a chance to occur.

The principle of RCM was focused on the level of severity when the interruption occurred. It firstly prioritizes the maintenance selection for the failure mode, which has the severity level. After that, it will be considered the failure mode, which has some of non-critical.

The criteria for determining the critical impact level can be followed as the Table 3.11 [2].

Table 3.11 The determination of critical impact level

Severity	Frequency	Critical impact
High	High	Very high
High	Medium	High
High	Low	Medium
High	Non-dominant	Non-analysis
Medium	High	High
Medium	Medium	Medium
Medium	Low	Low
Medium	Non-dominant	Non-analysis
Low	High	Medium
Low	Medium	Low
Low	Low	Non-critical
Low	Non-dominant	Non-analysis
None	High	Non-analysis
None	Medium	Non-critical
None	Low	Non-critical
None	Non-dominant	Non-analysis

3.3. Specification of preventive maintenance (PM)

To select the maintenance for each failure mode must be considered only the failure mode, which can be implemented by preventive maintenance. The RCM process uses a Logic Tree Analysis (LTA) structure that permits the analyst to quickly and accurately place each failure mode into one of four categories: (1) safety-related, (2) outage-related and (3) economics-related as shown in Figure 3.5. Based on the Figure 3.5 the maintenance criteria will be applied as following:

- Safety problem (A or D/A): the preventive maintenance should be defined for keeping the risk of damage within the acceptable rang by compromising in preventive maintenance cost.
- Outage problem (B or D/B): the preventive maintenance should be defined. But the preventive maintenance cost must be less than corrective maintenance cost plus outage cost (PM ≤ CM + OC).
- Economics problem (C or D/C): the preventive maintenance should be defined. But the preventive maintenance cost must be less than corrective maintenance cost or otherwise, it will be mark as Run to Fail.

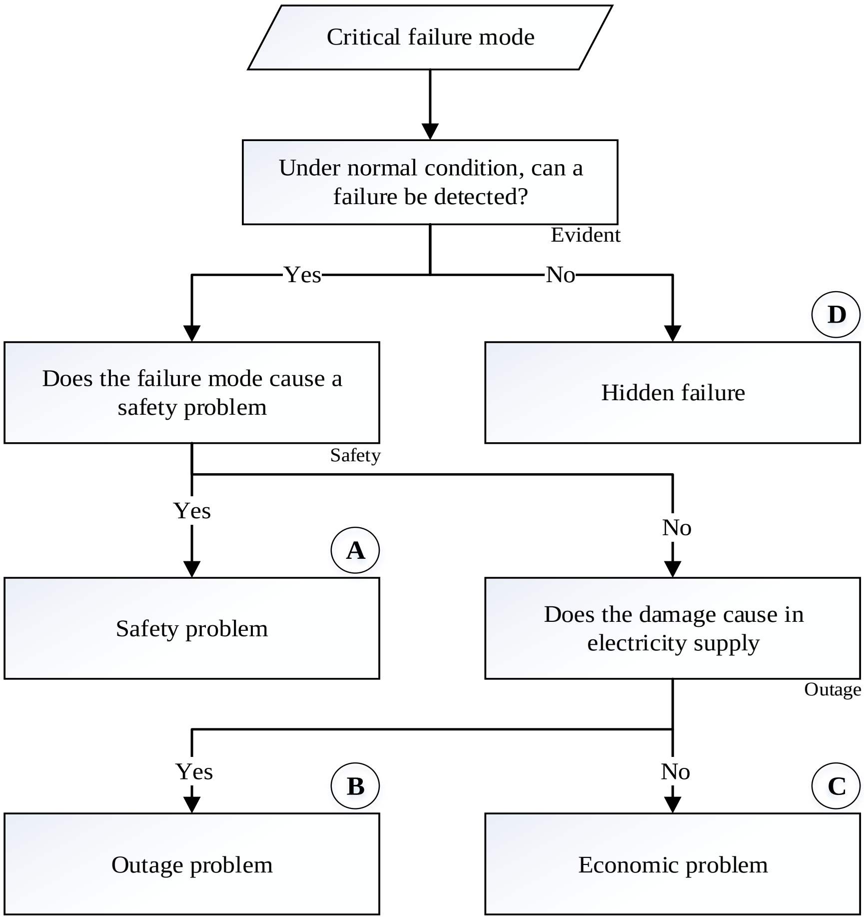

Figure 3.5 Logic Tree Analysis structure

The increments of maintenance activity frequency must be considered. These are applied the data of maintenance frequency for each activity and data of estimation about maintenance activity, which can be inquired from staffs of EDL. The Table 3.12 shows example for the evaluation of maintenance activity frequency, which will be applied to analyze the preventive maintenance cost when performing the maintenance activity at a defined frequency to get the most appropriate activity type and activity frequency in the best value.

Table 3.12 The maintenance activity frequency evaluation of EDL

Maintenance	**Frequency**	**Number of interruption decreased**
Tree trimming	Every 6 months	23 %
	Every 12 months	18 %
System patrolling, hot spot checking	Every 2 months	34 %
	Every 3 months	17 %
System inspection, maintenance of transformer	Every 3 months	40 %
	Every 4 months	25 %

The selection of maintenance activity must be considered the preventive maintenance comparing to the corrective maintenance. If the preventive maintenance cost is less than the corrective maintenance cost that means the maintenance activity frequency can be continued. On the other hand, the preventive maintenance cost is higher than corrective maintenance cost, it will be compared to the customer outage cost. If it is still higher than the customer outage cost, that activity will be not considered anymore as shown in the Figure 3.6.

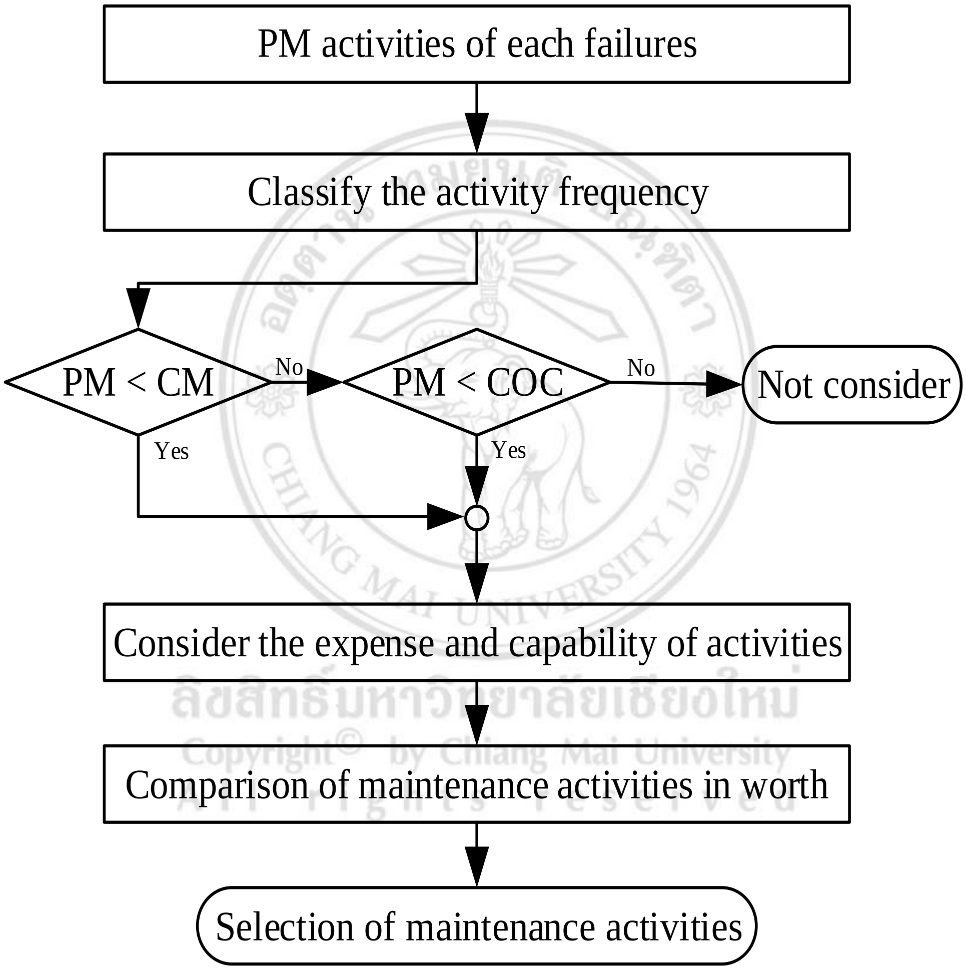

Figure 3.6 The process for selecting the frequency and PM activity

To perform the same type of maintenance activity in different frequency can be caused the difference of power interruption decrement. The evaluation data on the maintenance activity frequency is used for analyzing the number of power interruption reduction. If the frequency of maintenance activity is increasing, this will be caused the number of power interruption reduction and must be also calculated the increment of preventive maintenance cost and the effective value (EV) of preventive maintenance activity. Additionally, the corrective maintenance and customer outage cost reduction must be considered when the frequency of maintenance activity changes. The effective value of preventive maintenance activity can be calculated by the formula 6 as below:

$$EV = \frac{\text{Number of power interruption decreased} \times 10^{3}}{\text{Preventive maintenance budget increased}} \qquad (6)$$

The selection maintenance frequency increment can be considered from the effective value calculation by choosing the maintenance activity in sorting them by the value of largest to smallest. For the maintenance frequency decrement must be chosen to reduce the activity that prevents the power interruption, which is a critical failure mode or non-critical failure mode.

To consider the reduction of preventive maintenance activity frequency for the power interruption, which is a non-critical failure mode. It will be considered the effective value by comparing between an effective value of non-critical activity (EV_{non}) and an effective value of a critical activity ($EV_{critical}$). This can be reduced the frequency of non-critical activity if the effective value of a non-critical activity is less than or equal the effective value of a critical activity ($EV_{non} \le EV_{critical}$). The effective value of critical activity can be found as following the formula 7 below:

$$EV_{critical} = \frac{\sum_{i=1}^{n} PM_i \times EV_i}{\sum_{i=1}^{n} PM_i} \qquad (7)$$

Where:

n The number of activity that prevents the power interruption, which is a critical failure mode

PM_i The cost of preventive maintenance increased for activity i.

EV_i The effective value of activity i.

3.4. Selection of maintenance task

The analysis efforts to this point are used to select the final task, which applied the information from the previous step. The old maintenance plan and the new maintenance plan based on the principle of RCM are used for comparing to find the appropriate maintenance selection. The relationship between the reliability and the maintenance budget of the maintenance planning must be determined. This can be found from the evaluation information in the preventive maintenance investment of EDL as shown in the Table 3.13, the basic power supply characteristic of feeders as shown in Table 3.14 and the environmental characteristic around the feeder as shown in Table 3.15.

Table 3.13 The evaluation for PM investment of EDL

Interruption cause	**Environment**	**Number of interruption**		
		Without maintenance	**With decreased maintenance**	**With increased maintenance**
Tree	A lot	300 %	150 %	-50 %
	Not too much	150 %	70 %	-70 %
	Less	100 %	30 %	-80 %
	Clearing	-	-	-
Animal	In town	100 %	60 %	-30 %
	Outlying town	200 %	90 %	-40 %
Conductor	Bared	100 %	80 %	-50 %
	Insulated	60 %	50 %	-80 %
Insulator		200 %	60 %	-50 %
Switching and protecting equipment		100 %	60 %	-50 %
Transformer		-	-	-

Table 3.14 The basic power supply characteristic of feeder

Feeder	**Length (km)**	**Conductor (km)**			**Total transformer**
		Bared	**PIC**	**SAC**	
MSS 5.5	24.59	3	7.4	14.19	75
MSS 5.8	43.74	21.87	17.5	4.37	70

Table 3.15 The environmental characteristic around the feeder

Feeder	**Length (km)**	**Density of tree**			
		Much	**Medium**	**Less**	**Clearing**
MSS 5.5	24.59	-	-	11.7	12.89
MSS 5.8	43.74	-	9.5	10.53	23.7

Based on the evaluation information in the preventive maintenance and basic power supply characteristic of EDL, the relationship between the reliability and preventive maintenance budget can be shown in Figure 3.7.

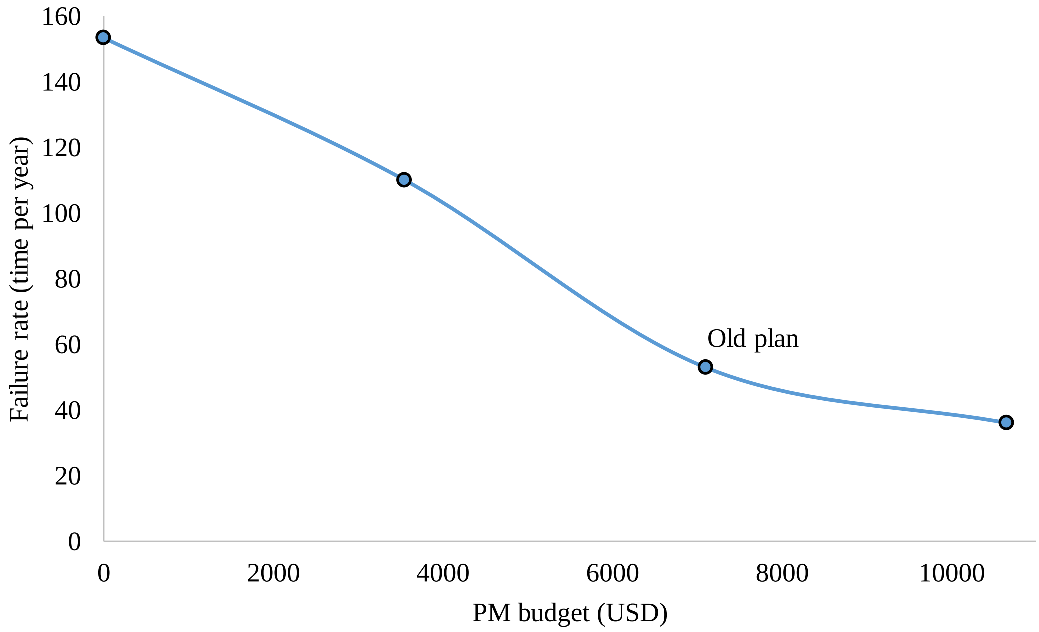

Figure 3.7 The preventive maintenance of EDL

The result of maintenance activity selection from the principle of RCM will be compared the old maintenance planning of EDL. This will be added or deleted the maintenance activity for improving the appropriate maintenance activity selection.

The comparison of maintenance plan should be considered the frequency of maintenance activity, which is based on the principle of RCM. Some maintenance activity of old maintenance plan may be over frequent if it can be reduced its budget for using to the other required activity. Besides that, the selection of appropriate maintenance activity must be considered the acquired maintenance budget.