CHAPTER 4

Result of analysis

The analysis result for this research based on the principle of RCM, which is applied to analyze the electrical distribution system of Phontong substation. This chapter introduces the result of analysis based on the data record of EDL.

4.1. System selection and data collection

The improvement of the electrical distribution system reliability, EDL has used the power interruption statistical data, including date of interruption, operation equipment, outage duration and interruption cause. The data is used to analyze and find the impact and the failure rate in each area. The system selection considers the number of interruption for reducing the expenses of spare parts, maintenance cost and outage costs.

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.

4.2. Failure mode and effect analysis

The relationship analysis between failure frequency and damage severity is applied to determine the critical impact for each interruption event. Table 4.1 shows the severity level, which is analyzed by the score of the impact level including power loss, number of customer and customer outage cost. The high level (H) is equal three points, medium level (M) is equal two point and low level (L) is equal one point. The sum of score range from one to three points corresponds to low level, the sum of score range from four to six corresponds to medium level, and the sum of score range from seven to nine corresponds to high level.

Table 4. 1 The severity level of each failure mode

Hardware	Action	Power loss	Total customer	Customer outage	Severity level
Conductor	Down tree	L	L	L	L
Conductor	Down tree	L	L	L	L
CB	Other	L	M	L	M
Re-closer	Animal	L	L	L	L
Re-closer	Tree	L	L	L	L
Insulator	Flashover	L	L	L	L
Drop out fuse	Burn	L	L	L	L
Drop out fuse	Break	L	L	L	L
DS	Arcing	L	L	L	L
DS	Other	L	L	L	L
CB	Other	L	M	L	M
Re-closer	Down tree	L	L	L	L
LA	Flashover	L	L	L	L
CB	Trip (Overload)	L	H	L	M
CB	Trip (Overload)	L	H	L	M
Conductor	Rain-Flashover	L	L	L	L
Pole	Accident	L	L	L	L
Fuse of Tr	Break	L	L	L	L
CB	Trip (Overload)	L	H	L	M
LA	Flashover	L	L	L	L
LA	Flashover	L	L	L	L
LA	Burn	L	L	L	L
Insulator	Flashover	L	L	L	L
Insulator+Conductor	Crash-Break	H	M	L	M
CB	Other	L	H	L	M
Re-closer	Tree	L	L	L	L
Re-closer	Tree	L	L	L	L
CB	Other	L	H	L	M
CB	Other	L	M	L	M
CB	Other	L	M	L	M
Transformer	Animal (cat)	M	L	L	M
Insulator	Flashover	L	M	L	M
Insulator	Flashover	L	L	L	L
Conductor	Span (under)	L	M	L	M
Transformer	Animal (snack)_PTT	M	M	L	M
Transformer	Other	L	H	L	M
LA	Flashover	L	L	L	L
DS	Other	L	L	L	L

Table 4.1 The customer outage cost impact level due to the interruption (continued)

Hardware	Action	Power loss	Total customer	Customer outage	Severity level
Insulator	Flashover	L	L	L	L
DS	Other	L	L	L	L
Insulator	Flashover	L	L	L	L
Insulator	Crash	L	L	L	L
Transformer	Animal (bird at bushing)	L	M	L	M
Conductor	Animal (bird at insulator)	L	L	L	L
Re-closer	Down tree	L	M	L	M
Re-closer	Down tree	L	M	L	M
Pole	Accident	L	M	L	M
Conductor	Break-Accident	M	L	L	M
CB	Other	L	M	L	M
Re-closer	Animal (snack at pole)	L	L	M	M
Drop out fuse	Animal (cat)	L	L	M	M
CB	Other	L	H	H	H

The failure frequency and damage severity are used for analyzing the failure mode and critical impact. The failure frequency is evaluated from the number of events, which occurred and affected the operation number of devices. The severity is evaluated from the impact due to interruption and costumer outage cost. The determination of the critical impact level for each failure mode has based on the Table 3.11 in Chapter 3. Any interruption event is non-critical will be not used for logic tree analysis as shown in Table 4.2.

Table 4. 2 Failure mode and effect analysis

Hardware	Failure mode			Impact			LTA
	Symptom	**Physical**	**Cause**	**Frequency**	**Severity**	**Critical**	
Conductor	Flash to ground		Down tree	M	L	L	Yes
Conductor	Flash to ground		Lightning struck a tree	M	L	L	Yes
CB	Trip (be able to re-operate)		Unknown	H	M	H	Yes
Re-closer	Trip and re-close		Re-closer operation from bird at an insulator	L	L	NC	No
Re-closer	Trip and re-close		Re-closer operation from tree	H	l	M	Yes
Insulator	Flash to ground		Lightning	L	L	NC	No
DOF	Burn	Crack	Damage to drop out fuse cutout	M	L	L	Yes
DOF	Burn	Broken	Equipment fails from fuse housing	M	L	L	Yes
DS	Flashover		Looseness	L	L	NC	No
DS		Dirt	Environment	M	L	L	Yes
CB	Trip and re-operate		Equipment fails	M	M	M	Yes
Re-closer	Trip and re-close		Re-closer operation from tree	H	L	M	Yes
LA	Flashover, Burn		Equipment fails	M	L	L	Yes
CB	Trip		Over load	M	M	M	Yes
CB	Trip		Over load	M	M	M	Yes
Conductor	Flash to ground		Tree branch touched the conductor	M	L	L	Yes
Pole		Broken	Car crashed the pole	M	L	L	Yes
Fuse of Tr	Burn	Broken	Equipment fails	L	L	NC	No
CB	Trip and re-operate		Equipment fails	M	M	M	Yes
LA	Flashover		Lightning	M	L	L	Yes
LA	Flashover		Lightning	M	L	L	Yes

Table 4.2 Failure mode and effect analysis (continued)

Hardware	Failure mode			Impact			LTA
	Symptom	Physical	Cause	Frequency	Severity	Critical	
LA	Burn	Crack	Equipment fails because of lightning	M	L	L	Yes
Insulator		Dirty	Environment	H	L	M	Yes
Insulator+Conductor		Broken	Accident from crane truck	L	M	L	Yes
CB	Trip and re-operate		Unknown	H	M	H	Yes
Re-closer	Trip and re-close		Re-closer operation from tree	H	L	M	Yes
Re-closer	Trip and lockout		Re-closer operation from down tree to conductor	H	L	M	Yes
CB	Trip and re-operate		Unknown	H	M	H	Yes
CB	Trip and re-operate		Unknown	H	M	H	Yes
CB	Trip and re-operate		Equipment fails	M	M	M	Yes
Transformer	Burn	Crack of low voltage bushing	Cat climbs to Tr bushing	M	M	M	Yes
Insulator		Contaminate, dirt	Environment	H	M	H	Yes
Insulator		Contamination, dirty	Environment	H	L	M	Yes
Conductor	Flash to ground		Tree branch falls down to the conductor	M	M	M	Yes
Transformer	Burn	Crack of low voltage bushing	Snake climbs to the Tr	M	M	M	Yes
Transformer		Dirt at bushing	Environment	L	M	L	Yes
LA		Contamination, dirty		M	L	L	Yes
DS	Arcing		Equipment fails	M	L	L	Yes
Insulator		Contaminate, dirt	Environment	H	L	M	Yes
DS		Contaminate, dirt	Environment	M	L	L	Yes
Insulator		Contamination	Environment	H	L	M	Yes
Insulator	Flashover		Crack	L	L	NC	No

Table 4.2 Failure mode and effect analysis (continued)

Hardware	Failure mode			Impact			LTA
	Symptom	Physical	Cause	Frequency	Severity	Critical	
Transformer	Flashover		Bird at Tr bushing	M	M	M	Yes
Conductor	Flash from conductor through insulator		Flash from conductor to cross beam because of bird at insulator	H	L	M	Yes
Re-closer	Trip and re-close		Re-closer operation from tree	H	M	H	Yes
Re-closer	Trip and re-close		Re-closer operation from tree	H	M	H	Yes
Pole		Broken	Truck crashed the pole	M	M	M	Yes
Conductor		Broken	Accident from truck crane	L	M	L	Yes
CB	Trip and re-operate		Equipment fails	M	M	M	Yes
Re-closer	Trip and re-close		Re-closer operation from snake climbs up the pole	L	M	L	Yes
Drop out fuse	Flashover	Broken	Damage to drop out fuse cutout from cat at the transformer	L	M	L	Yes
CB	Trip and re-operate		Unknown	H	H	VH	Yes

4.3. Specification of preventive maintenance

The power interruption due to the equipment failure can be affected to a large number of customers and wide area. The equipment quality and its working condition are the factors that affect the equipment failure. Inspection and preventive maintenance activity can help decrease these events. Additionally, the power outage caused by a down tree and animal can carry out by tree trimming activity, inspection activity, installation of animal guard an insulated conductor. The tree trimming implementation can also decrease the number of failure, which is caused by animals. But it is very difficult to implement the activity for the prevention of power outage because of its changeable behavior and its nature.

Based on the data of preventive maintenance for each failure mode as shown in Table 4.3, which can be implemented to prevent the causes that have three main maintenance activities such as distribution system inspection, hot spot checking, and tree trimming. For the maintenance task selection will be not considered the failure mode, which is the non-critical impact level.

Each failure mode will be placed into categories such as: Safety problem (A), Outage problem (B) and Economic problem (C) to implement the preventive maintenance as shown in Table 4.3.

Table 4. 3 Logic tree analysis

Failure mode			Logic tree analysis					
			Consequence					
Symptom	**Physical damage**	**Cause**	**A (S)**	**B (O)**	**C (E)**	**D (H)**	**Maintenance task**	**Prevent causes**
Flash to ground		Down tree	Y	N	N	N	System patrolling, tree trimming in risk	Tree trimming
Flash to ground		Lightning struck a tree	Y	N	N	N	System patrolling, tree trimming in risk	Tree trimming
Trip (be able to re-operate)		Unknown	N	N	N	Y	System patrolling and inspection	System inspection
Trip and re-close		Re-closer operation from tree	N	Y	N	N	System patrolling, tree trimming in risk	Tree trimming
Burn	Crack	Damage to drop out fuse cutout	N	Y	N	N	Hot spot correction, equipment repair	Hot spot checking
Burn	Broken	Equipment fails from fuse housing	Y	N	N	N	Hot spot correction, equipment repair	Hot spot checking
	Dirt	Environment	N	N	Y	N	System inspection, system patrolling	System inspection
Trip and re-operate		Equipment fails	N	Y	N	N	Hot spot correction, equipment repair	Hot spot checking
Trip and re-close		Re-closer operation from tree	N	Y	N	N	System patrolling, tree trimming in risk	Tree trimming
Flashover, Burn		Equipment fails	Y	Y	N	N	Hot spot correction, equipment repair	Hot spot checking

Table 4.3 Logic tree analysis (continued)

Failure mode			Logic tree analysis					
			Consequence					
Symptom	**Physical damage**	**Cause**	**A (S)**	**B (O)**	**C (E)**	**D (H)**	**Maintenance task**	**Prevent causes**
Flash to ground		Tree branch touched the conductor	Y	N	N	N	System patrolling, tree trimming in risk	Tree trimming
	Broken	Car crashed the pole	Y	N	N	N	System inspection, equipment repair	System inspection
Trip and re-operate		Equipment fails	N	Y	N	N	Hot spot correction, equipment repair	Hot spot checking
Flashover		Lightning	Y	N	N	N	Hot spot correction, equipment repair	Hot spot checking
Flashover		Lightning	Y	N	N	N	Hot spot correction, equipment repair	Hot spot checking
Burn	Crack	Equipment fails because of lightning	Y	N	N	N	Hot spot correction, equipment repair	Hot spot checking
	Dirty	Environment	N	N	Y	N	System inspection, system patrolling	System inspection
	Broken	Accident from crane truck	Y	N	N	N	System inspection, equipment repair	System inspection
Trip and re-operate		Unknown	N	N	N	Y	System patrolling and inspection	System inspection
Trip and re-close		Re-closer operation from tree	N	Y	N	N	System patrolling, tree trimming in risk	Tree trimming

Table 4.3 Logic tree analysis (continued)

Failure mode			Logic tree analysis					
			Consequence					
Symptom	**Physical damage**	**Cause**	**A (S)**	**B (O)**	**C (E)**	**D (H)**	**Maintenance task**	**Prevent causes**
Trip and lockout		Re-closer operation from down tree to conductor	N	Y	N	N	System patrolling, tree trimming in risk	Tree trimming
Trip and re-operate		Unknown	N	N	N	Y	System patrolling and inspection	System inspection
Trip and re-operate		Unknown	N	N	N	Y	System patrolling and inspection	System inspection
Trip and re-operate		Equipment fails	N	Y	N	N	Equipment repair	System inspection
Burn	Crack of low voltage bushing	Cat climbs to Tr bushing	Y	N	N	N	Animal guard installation, equipment repair	System inspection
	Contaminate, dirt	Environment	N	N	Y	N	System inspection, system patrolling	System inspection
	Contamination, dirty	Environment	N	N	Y	N	System inspection, system patrolling	System inspection
Flash to ground		Tree branch falls down to the conductor	Y	N	N	N	System patrolling, tree trimming in risk	Tree trimming
Burn	Crack of low voltage bushing	Snake climbs to the Tr	Y	N	N	N	Animal guard installation, equipment repair	System inspection
	Dirt at bushing	Environment	N	N	Y	N	System inspection, system patrolling	System inspection

Table 4.3 Logic tree analysis (continued)

Failure mode			Logic tree analysis					
			Consequence					
Symptom	**Physical damage**	**Cause**	**A (S)**	**B (O)**	**C (E)**	**D (H)**	**Maintenance task**	**Prevent causes**
	Contamination, dirty	Environment	N	N	Y	N	System inspection, system patrolling	System inspection
Arcing		Equipment fails	Y	N	N	N	Hot spot correction, equipment repair	Hot spot checking
	Contaminate, dirt	Environment	N	N	Y	N	System inspection, system patrolling	System inspection
	Contaminate, dirt	Environment	N	N	Y	N	System inspection, system patrolling	System inspection
	Contamination	Environment	N	N	Y	N	System inspection, system patrolling	System inspection
Flashover		Bird at Tr bushing	Y	N	N	N	Animal guard installation, hot spot correction	System inspection
Flash from conductor through insulator		Flash from conductor to crossbeam because of bird at insulator	Y	N	N	N	Animal guard installation	System inspection
Trip and re-close		Re-closer operation from tree	N	Y	N	N	System patrolling, tree trimming in risk	Tree trimming
Trip and re-close		Re-closer operation from tree	N	Y	N	N	System patrolling, tree trimming in risk	Tree trimming
	Broken	Truck crashed the pole	Y	N	N	N	System patrolling, equipment repair	System inspection

Table 4.3 Logic tree analysis (continued)

Failure mode			Logic tree analysis					
			Consequence					
Symptom	**Physical damage**	**Cause**	**A (S)**	**B (O)**	**C (E)**	**D (H)**	**Maintenance task**	**Prevent causes**
	Broken	Accident from truck crane	Y	N	N	N	System patrolling, equipment repair	System inspection
Trip and re-operate		Equipment fails	N	Y	N	N	Equipment repair	System inspection
Trip and re-close		Re-closer operation from snake climbs up the pole	N	Y	N	N	Animal guard installation, system patrolling	System inspection
Flashover	Broken	Damage to drop out fuse cutout from cat at the transformer	Y	N	N	N	Animal guard installation	System inspection
Trip and re-operate		Unknown	N	N	N	Y	System patrolling and inspection	System inspection

From the power interruption data, the critical failure caused mostly down tree, equipment and animals. The system should be established the improvement and maintenance. Therefore, the maintenance activities can be established as shown in the Table 4.4

Table 4. 4 Workload for maintenance activity

Maintenance activity	workload
Tree trimming	31.73 cct-km
Animal guard installation	11 units
Hot spot checking and defected equipment correcting	22 points
Insulator replacement	2 point
Drop out fuse replacement	3 point
Incoming lead cable of distribution transformer replacement	1 unit

The data of estimation about maintenance activity, which is inquired from the staff of EDL will be applied to compare the budget and the value of preventive maintenance activity. This includes the maintenance activity cost, preventive maintenance cost, and power interruption data. The comparison will be known the preventive maintenance cost, corrective maintenance cost and customer outage cost due to the power interruption as shown in Table 4.5 and also can be known the effective value (EV) for each activity as shown in Table 4.6.

Table 4. 5 The comparison of PM cost, CM cost and CCO cost due to the interruption

Maintenance activity	Frequency	PM increase	CM decrease	CCO decrease	Consideration
Tree trimming	Every 6 months	$ 2,000	$ 3,466.81	$ 3,206.10	Yes
	Every 12 months	$ 1,300	$ 2,713.15	$ 2,509.12	Yes
Hot spot checking	Every 2 months	$ 3,900	$ 5,124.85	$ 4,739.45	Yes
	Every 3 months	$ 2,600	$ 2,562.42	$ 2,369.73	Yes
System inspection	Every 3 months	$ 4,800	$ 6,029.23	$ 5,575.83	Yes
	Every 4 months	$ 3,600	$ 3,768.27	$ 3,768.27	Yes

Table 4. 6 The effective value for maintenance activity

Maintenance activity	**Frequency**	**Decreased interruption**	**Increased PM**	**EV**
Tree trimming	Every 6 months	8	$ 2,000	4.03
	Every 12 months	6	$ 1,300	4.85
Hot spot checking	Every 2 months	6	$ 3,900	1.57
	Every 3 months	3	$ 2,600	1.18
System inspection	Every 3 months	14	$ 4,800	2.92
	Every 4 months	9	$ 3,600	2.43

In this case, based on the failure mode and effect analysis and the old maintenance planning frequency of EDL was found that the system inspection for distribution system has a lot of power interruption events, which are non-critical failure mode. Consequently, the maintenance planning will be considered the maintenance frequency reduction for decreasing the preventive maintenance budget for $ 2,400 per year from the maintenance frequency every three months to every six months per year. However, the reduction of system inspection activity frequency may result in the power interruption increased approximately 5 failures. Therefore, this can be calculated the effective value (EV_{non}) for this activity and it has the value of 2.19.

The consideration for reduction of non-critical activity has to compare the value of the critical activity that is based on the data in Table 4.6. The selection of tree trimming activity every six months and hot spot checking activity every three months. The critical effective value of the maintenance plan can result of 2.42, which is in the condition for the non-critical effective value is less than the critical effective value ($EV_{non} \leq EV_{critical}$). Consequently, the maintenance planning can be reduced the frequency of system inspection from every three months to every six months per year for reducing the preventive maintenance budget, which will be used to the hot spot checking activity frequency from every six months to every three months per year.

Based on the old maintenance planning frequency of EDL, which has the non-critical effective value of 2.19. This non-critical effective value will be compared to the feasibility of maintenance planning based on the principle of RCM. If the effective value is in the condition ($EV_{non} \leq EV_{critical}$) that means that maintenance planning can be used to implement for reducing the power interruption as shown in Table 4.7.

Table 4. 7 The comparison of effective value for each maintenance planning

Plan	Tree trimming	Hot spot checking	System inspection	EV_{non}	$EV_{critical}$
X	Every 6 months	Every 6 months	Every 3 months	2.19	-
RCM 1	Every 6 months	Every 6 months	Every 6 months	2.19	-
RCM 2	Every 12 months	Every 3 months	Every 6 months	2.19	2.40
RCM 3	Every 6 months	Every 3 months	Every 6 months	2.19	2.42
RCM 4	Every 12 months	Every 2 months	Every 6 months	2.19	2.39
RCM 6	Every 6 months	Every 2 months	Every 6 months	2.19	2.40

4.4. Selection of maintenance task

The current preventive maintenance planning of EDL is shown at the plan X as shown in Table 4.8. The other row of the table presents the possibility of preventive maintenance planning, which will be used to decide and compare for the maintenance selection of distribution system. The Figure 4.1 shows the comparison between the old maintenance planning and the possible maintenance planning of EDL.

Table 4. 8 The comparison of maintenance planning budget

Plan	Tree trimming	Hot spot checking	System inspection	PM budget
X	Every 6 months	Every 6 months	Every 3 months	$ 7,100
RCM 1	Every 6 months	Every 6 months	Every 6 months	$ 5,700
RCM 2	Every 12 months	Every 3 months	Every 6 months	$ 6,000
RCM 3	Every 6 months	Every 3 months	Every 6 months	$ 7,000
RCM 4	Every 12 months	Every 2 months	Every 6 months	$ 7,300
RCM 6	Every 6 months	Every 2 months	Every 6 months	$ 8,300

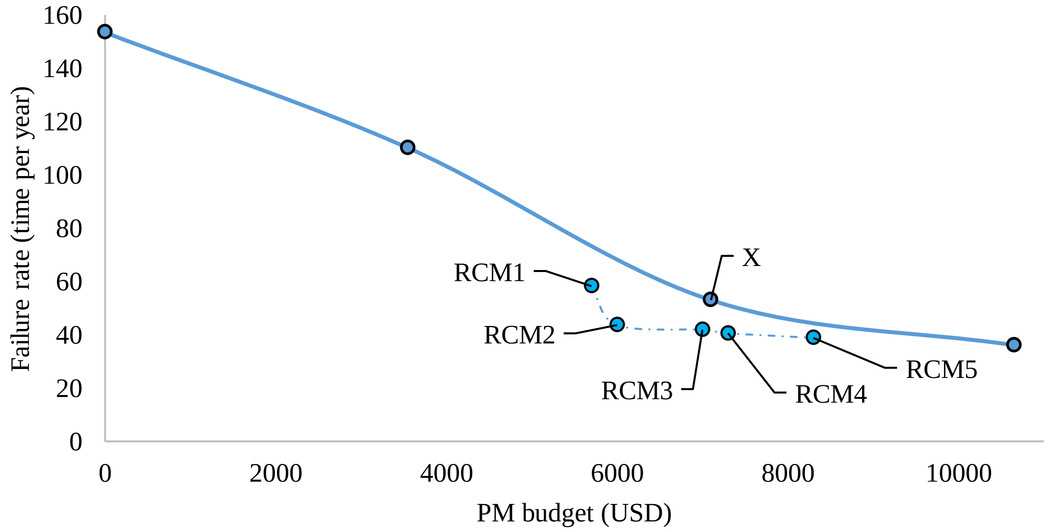

Figure 4. 1 The comparison of maintenance planning

According to the graph of comparison between the maintenance planning, the plan of RCM 2 and RCM 3 are appropriate within the budget is unchanged. Because they use a less budget comparing to the old planning and they also can be decreased the power interruption that means the system reliability is also improved. If the budget of maintenance planning can be increased, the plan RCM 4 and RCM 5 can be selected depending on the received budget. These plans can be helped the better for preventing the power interruption.

Another way to reduce the number of failures is increasing the preventive maintenance activity frequency, such as tree trimming activity, hot spot checking activity, and system inspection activity. But should be considered the relationship between outage cost and preventive maintenance budget. While the activity frequency is increased, the preventive maintenance budget is also rising. But the advantage is outage cost reduction.

The Figure 4.2 shows the relationship between the outage cost curve and the preventive maintenance budget curve for tree trimming activity. The both of the curves summation has resulted in an effective curve, which has the minimum point value is 6,501. At this point corresponds to the appropriate maintenance planning for the tree trimming activity frequency of distribution system.

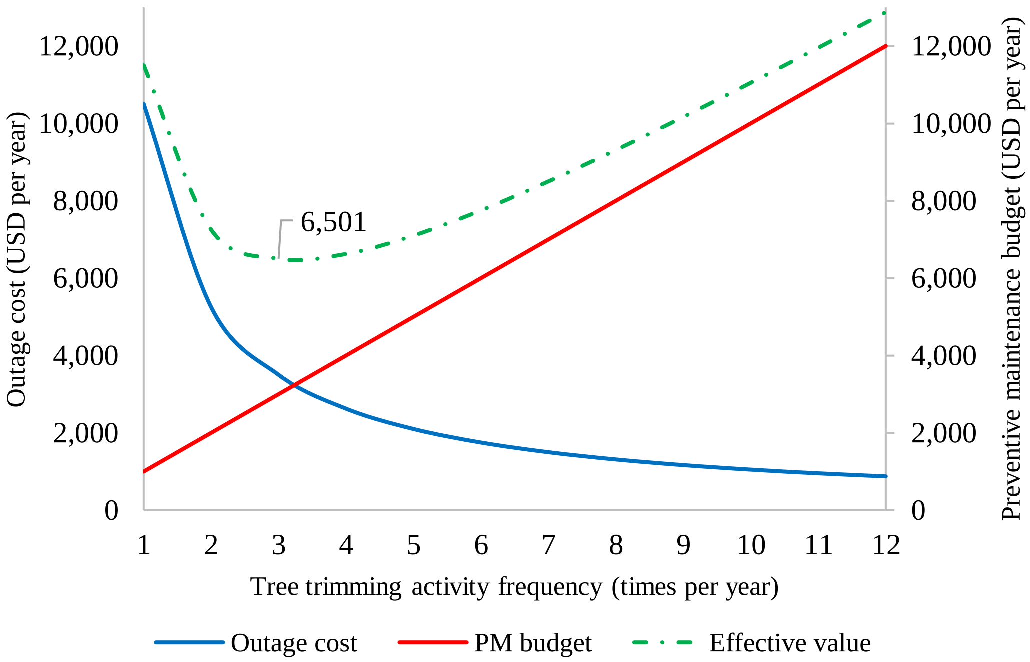

Figure 4. 2 The comparison graph for tree trimming activity

The Figure 4.3 shows the relationship between the outage cost curve and the preventive maintenance budget curve for hot spot checking activity. The both of the curves summation has resulted in an effective curve, which has the minimum point value is 3,920. At this point corresponds to the appropriate maintenance planning for the hot spot checking activity frequency of distribution system.

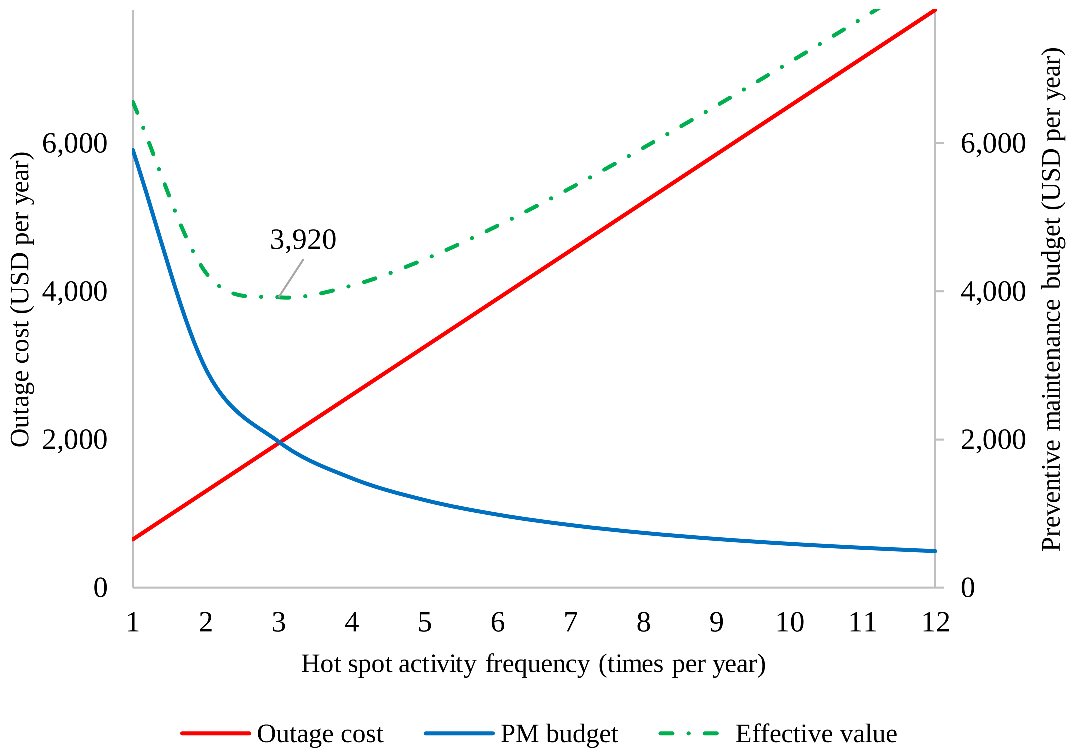

Figure 4. 3 The comparison graph for hot spot checking activity

The Figure 4.4 shows the relationship between the outage cost curve and the preventive maintenance budget curve for hot system inspection activity. The both of the curves summation has resulted in an effective curve, which has the minimum point value is 10,797. At this point corresponds to the appropriate maintenance planning for the system inspection activity frequency of distribution system.

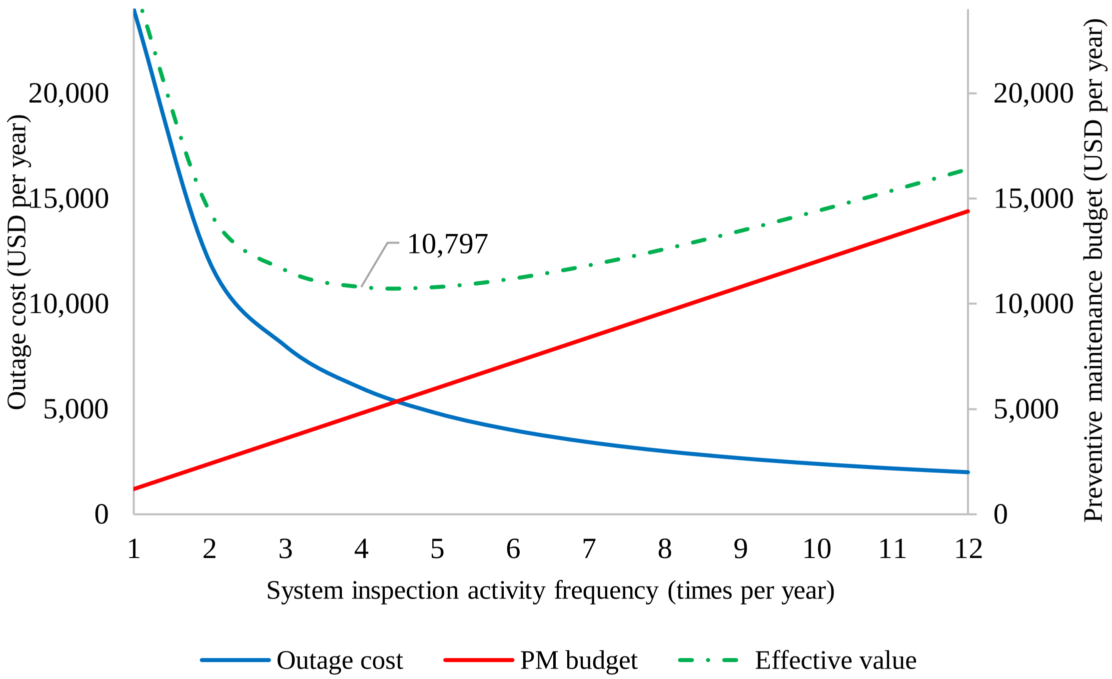

Figure 4. 4 The comparison graph for system inspection activity

From plot of comparison above, the graphs have resulted that at the minimum point of the effective value curve is the appropriate maintenance plan. The selection of maintenance activities depends on the tools, budget and the EDL's policy. In this case of study, the selection of maintenance plan at the minimum point of the effective curve using the principle of RCM can help reduce the power interruption. For tree trimming activity, the minimum point of the effective value has corresponded to the three times per year of PM activity frequency. For hot spot checking activity, the minimum point of the effective value has corresponded to the three times per year of PM activity frequency. For system inspection activity, the minimum point of the effective value has corresponded to the four times per year of PM activity frequency.

Based on the comparison graphs of three maintenance activities was found that the minimum of the effective value curve has the total of PM budget required for $ 9,750 including tree trimming activity for $ 3,000, hot spot checking activity for $ 1,950 and system inspection activity for $ 4,800 as shown in Table 4.9 and Figure 4.5.

Table 4. 9 The budget of maintenance activity using RCM curve plot

Maintenance activity	**PM budget**	**Expected outage reduction**
Tree trimming	$ 3,000	$ 3,501
Hot spot checking	$ 1,950	$ 1,970
System inspection	$ 4,800	$ 5,997

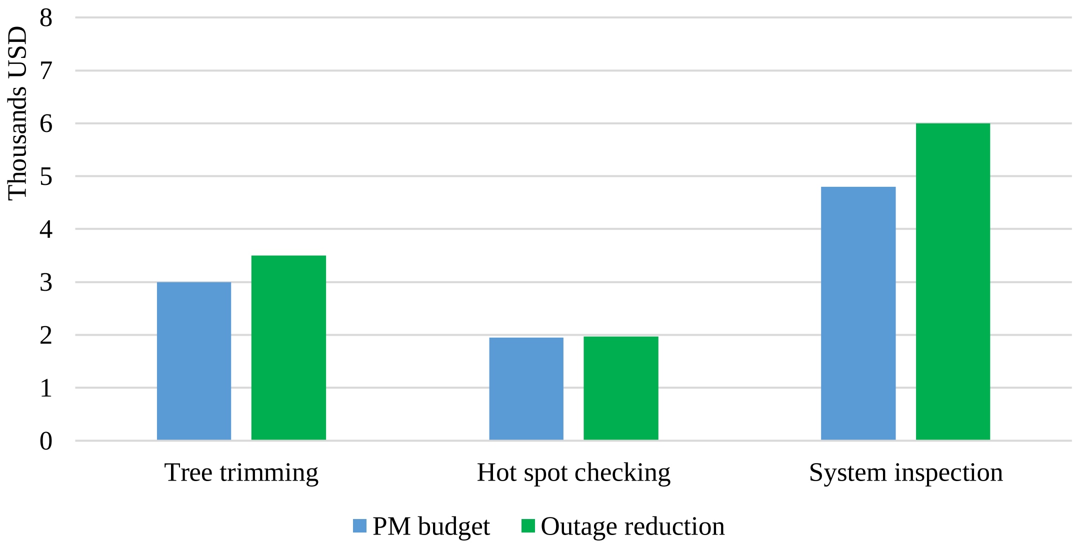

Figure 4. 5 The comparison between PM budget and expected outage reduction