Reliability Centered Maintenance (RCM) Implementation on PEA Power Distribution Systems: A Case Study of Bang-Pa-In Branch Office

Watchara Pobporn*, Onurai Noohawm, and Dulpichet Rerkpreedapong

Abstract— *This paper describes a Reliability Centered Maintenance (RCM) implementation on PEA power distribution systems. In order to achieve a cost-effective maintenance program, RCM is to prioritize the failure modes according to their effects, and then to select the effective maintenance activities for those failure modes. Preventive maintenance (PM) activities are mainly focused on the RCM program driven by the marginal benefit-to-cost ratio (B/C) between outage costs and maintenance costs. For a case study, Bang Pa In branch office located in Phra Nakhorn Si Ayutthaya Province, one of local power distribution utilities of Provincial Electricity Authority Central Area 1 (PEA C1) is selected for RCM implementation.*

***Keywords*—** **Power distribution reliability, maintenance planning, cost-effective maintenance, failure modes.**

1. INTRODUCTION

All industrial units require a reliable production process for sustainable survival in growing competition in today's economy. It is apparent that the continuity of power supply is essential to the function of industrial processes.

Therefore, power distribution systems operated by electric utilities must provide even more reliable electrical power to serve such requirement. This has become the primary objective of electric utilities to maintain their power distribution infrastructure at peak reliability levels.

Reliability Centered Maintenance (RCM) is a method of maintenance optimization widely used in global industries. In this paper, RCM is modified to a simple version well suited for applications to PEA power distribution networks. The main concept of the modified RCM is to prioritize the failure modes according to their effects, and then to select the effective maintenance activities for those failure modes. Preventive maintenance (PM) activities are mainly focused on the RCM program taking into account the marginal benefit-to-cost ratio (B/C) between outage costs (OC) and maintenance costs.

In this paper, the modified RCM is applied to power distribution systems of a PEA local utility, Bang Pa In branch office in Phra Nakhorn Si Ayutthaya Province in Central Area 1 of Provincial Electricity Authority of Thailand (PEA C1). The method is illustrated in step by step procedure. The PM program resulted from the proposed RCM guarantees the cost effectiveness, and reduces the amount of corrective maintenance (CM) and outage costs of both PEA and their customers.

2. OVERVIEW OF RCM

Reliability centered maintenance is a qualitative method for determining applicable and effective preventive maintenance tasks to preserve the primary function of selected components or systems. RCM has been widely used in a number of industries since it increases cost effectiveness of maintenance programs, and provides a better understanding of criticality of failure modes that interrupt the system from functioning. The general RCM process [1]-[4] is summarized in the following steps.

1. List the critical components and define their functions

2. Identify the dominant failure modes for each chosen component, and then prioritize the failure mode criticality determined from their failure history and consequences.

3. Determine preventive maintenance tasks for those critical failure modes.

4. Formulate an RCM program.

5. Evaluate the worth of RCM Program including cost analysis.

3. Modified RCM and Case Study

The RCM procedure is modified to a simple version well suited for applications with PEA power distribution networks. It is presented in four steps as follows.

Step 1: Feeder Selection and Information Collection

Step 2: Definition of Feeder Boundary and Function

Step 3: Failure Modes and Effects Analysis

Step 4: Preventive Maintenance Task Selection

The above steps are illustrated through an application

W. Pobporn (corresponding author) is with the Department of Electrical Engineering, Faculty of Engineering, Kasetsart University and with Engineering & Maintenance Division, Provincial Electricity Authority (PEA), Area 1 (Central), Asia Rd., Hantra, Phra Nakhorn Si Ayutthaya 13000, Thailand. Phone: +66-35-241-142 ext. 31413; Fax: +66-35-323-867; E-mail: watcharapob@hotmail.com, watchara.pob@pea.co.th

O. Noohawm and D. Rerkpreedapong are with the Department of Electrical Engineering, Faculty of Engineering, Kasetsart University, 50 Ngamwongwan Rd., Ladyao, Chatuchak, Bangkok, 10900, Thailand. Phone: 66-2-797-9999 ext.1543; E-mail: dulpichet.r@ku.ac.th

to a case study, which is Bang Pa In branch office. It is one of twenty branch offices in PEA C1, supplying electricity to 35,155 customers. The Bang Pa In branch office is responsible for 8 substations with 441 circuit-km of 22-kV power distribution system. In the case study, the proposed RCM method is applied to 3 critical substations including 26 feeders that supply electrical power to large industrial and commercial customers.

***Step 1**: Feeder Selection and Information Collection.*

The first step of RCM is the selection of power distribution feeders. To do this task, PEA maintenance data must be collected such as technical documents, interruption records, historical maintenance tasks data and maintenance expenses. The interruption records from year 2010 to September 2013 are shown in Table 1. Those interruptions were caused by unknown causes, equipment failures such as fuses, insulators and cable spacers, animals, and lightning strikes.

Table 1. Number of Interruptions by Failure Causes

Failure causes	Substation		
	BKS	BNL	BNM
Equipment failures	10	4	3
Unknown	26	22	6
Birds	1	1	0
Snakes	2	0	0
Lightning strikes	0	0	1

In this step, the interruption records are considered to select a few significant distribution feeders for RCM implementation. They are selected from the outage cost ranking of all feeders of Bang Pa In branch office. Each feeder outage cost is a sum of PEA and customer outage costs as described in equations (1) to (4). As a result, feeders BKS06, BNL01, BNL03 and BKS04 are selected because their outage costs as given in Table 2. are higher than the others as shown in Fig. 1. Then, the single-line diagrams of those feeders are prepared, interruption statistic of selected feeder in the next step.

$$FOC^i = \sum_k FOC_k^i = \sum_k (OC_k^{i,PEA} + OC_k^{i,Cust}) \quad (1)$$

$$OC_k^{i,PEA} = ICA_{PEA} \times \lambda^i \quad (2)$$

$$OC_k^{i,Cust} = ICPE_{Cust.} \times \lambda^i \quad (3)$$

$$ICA_{PEA} = CM + LossLoad \quad (4)$$

where

FOC^i Total outage cost of feeder i (Baht)

$OC_k^{i,PEA}$ PEA outage cost of feeder i (Baht)

$OC_k^{i,Cust}$ Customer outage cost of feeder i (Baht)

λ^i Failure rate of feeder i (events/yr)

ICA_{PEA} Average PEA interruption cost per event (Baht/event)

$ICPE_{Cust}$ Customer interruption cost per event (Baht/event) [9].

CM Average corrective maintenance cost per event (Baht/event).

LossLoad Average revenue losses due to interruptions per event (Baht/event)

k Interruption cause k.

Then, the benefits resulted from mitigating an interruption cause by associated PM is determined from (5).

$$B_k^i = \eta_k \times FOC_k^i \quad (5)$$

where

B_k^i Benefits from mitigating interruption cause k by associated PM of feeder i (Baht).

FOC_k^i Feeder outage cost due to interruption cause k of feeder i (Baht).

η_k Effectiveness ratio of PM mitigating interruption causes k.

Table 2. FOC of Selected Feeders

Feeder	Total FOC(Baht)
BKS06	66,094,209.66
BNL01	52,875,367.72
BNL03	46,265,946.76
BKS04	39,656,525.79

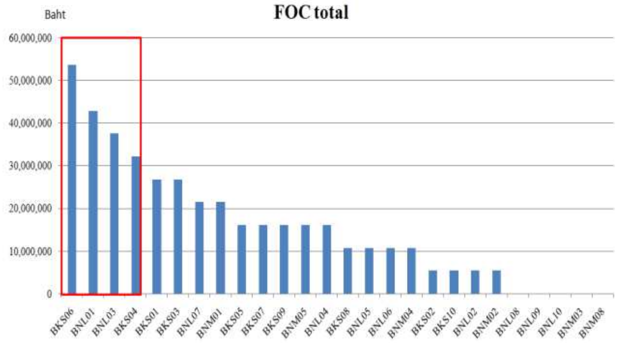

Fig.1. FOC in all feeders.

Step 2: Definition of Feeder Boundary and Function.

In this step, the boundary of all selected feeders is first defined to frame the scope of analysis. It will also help the RCM team members to focus on the targeted areas. In this work, single-line diagrams of the feeders together with geographic maps of service areas of Bang Pa In branch office are used to define the boundaries as shown in Fig. 2 to 4. For each feeder, the boundary covers all medium-voltage equipment. Then, the primary function of each feeder that RCM wishes to preserve is delivering electrical power from the substation to all distribution transformers continuously.

Fig.2. Geographic maps of service areas of Bang Pa In branch office.

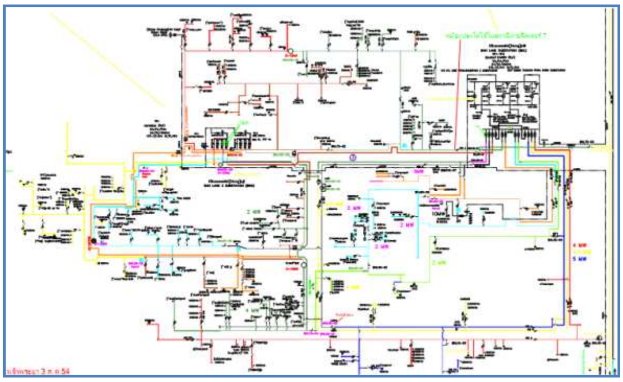

Fig.3. Single line diagram of BNL & BNM substations

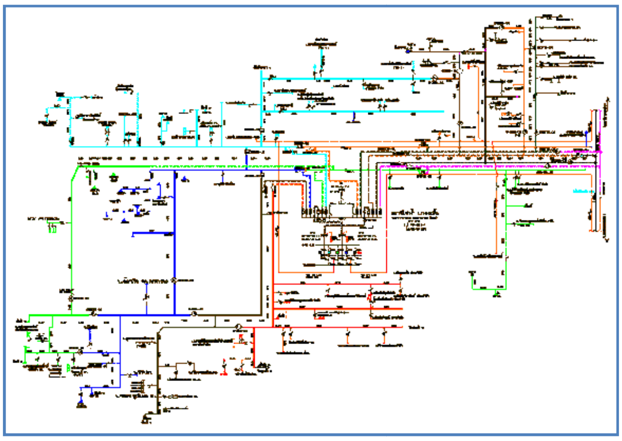

Fig.4. Single line diagram of BKS substations

Step 3: Failure modes and Effects Analysis.

After the primary function of the systems has been specified in the previous step, all dominant failure modes which interrupt the function must be determined. In this paper, the failure mode is defined as the dominant causes that interrupt power delivery. Thus, all failure modes and their effects in terms of FOC are given in Table 2.

Table 2. Feeder failure modes and effects analysis

Feeder	Failure modes	FOC(Baht)
BKS06	Unknown	66,094,210
BNL01	Unknown	39,656,526
	Equipment Failure	13,218,842
BNL03	Unknown	33,047,105
	Equipment Failure	13,218,842
BKS04	Unknown	19,828,263
	Snake	13,218,842
	Bird	6,609,421

Step 4: Preventive Maintenance Task Selection

The objective of this step is to select the optimal PM tasks that achieve the highest reliability worth as presented in terms of a reduction of FOC. In other words, the methodology is designed to find the most cost-effective maintenance tasks. Here, the cost is all expenses of maintenance tasks including hardware costs, labor costs, etc. PM tasks selected for this case study including replacement of bare conductors with spaced aerial cables (SAC), cable spacer maintenance, bird guards or snake guards installation and tree trimming are shown in Table 3. The marginal benefit-to-cost ratio (B/C) between outage costs and maintenance costs is considered to achieve effective PM task selection in equation (5). The costs of maintenance activities are presented in Table 4.

Table 3. Failure modes and associated PM tasks

Failure modes	PM tasks
Unknown	Replacement of bare conductor with SAC
	Cable spacer maintenance
	Bird guard installation
	Snake guard installation
	Tree trimming
Equipment Failures	Replacement of bare conductor with SAC
	Bird guard installation
	Snake guard installation
	Cable spacer maintenance
Snake	Snake guard installation
	Replacement of bare conductor with SAC
Bird	Bird guard installation
	Replacement of bare conductor with SAC

Table 4. Average costs of maintenance activities

Maintenance Task	Average Costs	Unit
Tree trimming	1,083	Baht/km
Snake Guard installation	110	Baht/set
Bird Guard installation	1,000	Baht/set
Replacement of bare conductor with SAC	1,000,000	Baht/cct-km
Cable spacer maintenance	61,700	Baht/km

For example, all PM tasks ranked by marginal benefit-to-cost ratio for BNL01 are shown in Table 5.

Table 5. Ranking of PM tasks for BNL01

Failure modes	PM tasks	B/C
Unknown	Tree trimming	183.16
Unknown	Snake Guard Installation	72.10
Unknown	Bird Guard Installation	38.33
Equipment Failures	Snake Guard Installation	33.65
Equipment Failures	Bird Guard Installation	17.89
Unknown	Cable Spacer maintenance	3.21
Equipment Failures	Cable Spacer maintenance	1.50
Unknown	Replacement of bare conductor with SAC	0.20
Equipment Failures	Replacement of bare conductor with SAC	0.09

For feeder BNL01, the optimal PM tasks which attain the highest marginal B/C ratio are tree trimming, bird guards and snake guards installation and cable spacer maintenance. The marginal benefit-to-cost ratio (B/C) between outage costs and maintenance costs is considered for the effective PM task selection (all dots above red line) for all feeders as shown in Fig. 5 to 8.

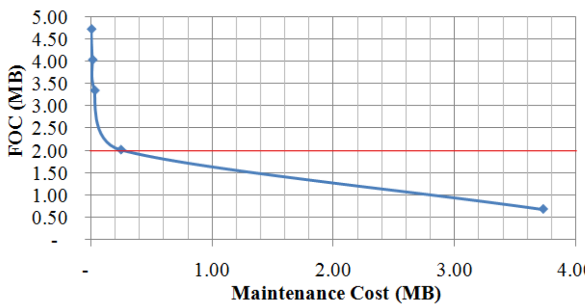

Fig.5. The Maintenance Cost and FOC of BNL01

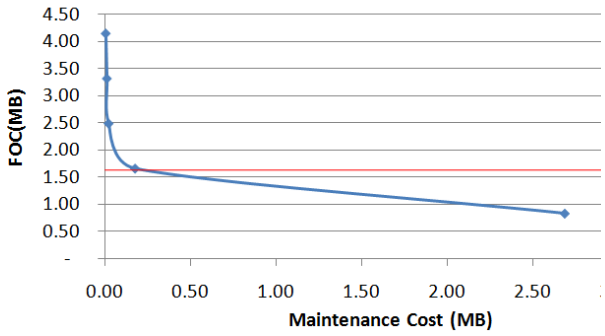

Fig.6. The Maintenance Cost and FOC of BKS06

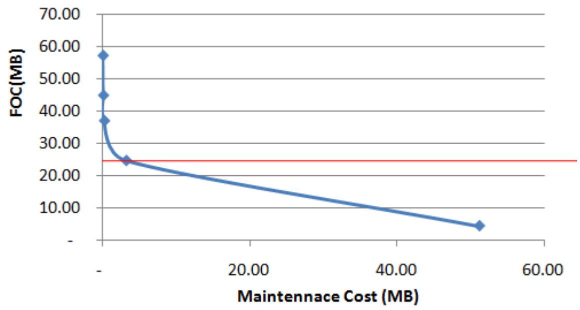

Fig.7. The Maintenance cost and FOC of BNL03

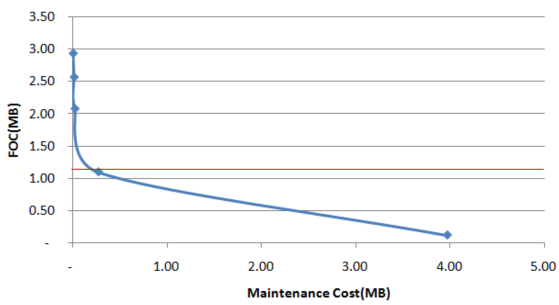

Fig.8. The Maintenance Cost and FOC of BKS04

The total cost of selected PM tasks versus a reduction of feeder outage costs are shown in Table 6. for each feeder.

Table 6. Total cost of PM tasks versus a reduction of FOC

Selected Feeder	Maintenance Cost (Baht)	FOC reduction (Baht)
BKS06	175,774.94	2,488,446.99
BNL01	246,053.28	2,714,092.63
BNL03	3,166,873.10	32,690,592.66
BKS04	270,645.44	1,834,114.32
Total	3,859,346.76	39,727,247

4. CONCLUSION

In this paper, Reliability Centered Maintenance (RCM) is implemented on PEA power distribution systems. In order to achieve a cost-effective maintenance program, RCM is to prioritize the failure modes according to their effects, and then to select the effective maintenance activities for those failure modes. Preventive maintenance (PM) activities are mainly focused on the RCM program driven by the marginal benefit-to-cost ratio (B/C) between outage costs and maintenance costs. The PM program resulted from the proposed RCM guarantees the cost effectiveness, and reduces the amount of corrective maintenance (CM) and outage costs of both PEA and their customers.

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