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Matlab Code to Analyze the Reliability Improvement of Electrical Distribution System Using Reliability Centered Maintenance

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Abstract: Electrical power on demand is one of the fundamental requirements of a modern society. It is essential to provide electrical power to the every consumer by the electrical distribution system with high degree of reliability in such a way that it is cost effective to both the consumers as well as the suppliers. This work is based on the analysis of power interruption data, different maintenance activities and selection of proper equipment for maintenance to improve the reliability of a distribution sub-station using Reliability Centered Maintenance (RCM) method. RCM will optimize reliability based maintenance activities with the help of different reliability indices. This paper also includes a comparative analysis between the conventional maintenance, Preventive Maintenance (PM) and RCM. A MATLAB code is developed to analyze the whole method by using a common interface for different input data of a distribution substation.

Keywords: Distribution system, Interruption, preventive Maintenance (PM), MATLAB, Reliability, Reliability Centered Maintenance (RCM), Reliability indices.

I. INTRODUCTION

With the advent of technologies, the demand for electricity is increasing day by day. The customers are becoming more sensitive to any electrical disturbances and demanding high degree of reliable and quality of power supply. So it is necessary to provide uninterrupted power supply to the every consumer with high degree of reliability. Moreover, failure statistics of each of the equipments of the electrical distribution system itself leads to the greatest risk to the interrupted power supply to the consumers. Since distribution systems have received less attention than the generating or transmitting station because they are less capital intensive and their failure causes more localized effect.

To improve the reliability of distribution system, many evaluation methods are proposed in [2]-[3]. This paper presents RCM method to improve the reliability of the distribution system. RCM is not a new concept but its practical application has still not been fully developed.[12]

As the demand for electrical power is increasing, the complexity of the system is also increasing simultaneously. And this increases the failure rate of the equipments. This can only be reduced by redesigning the system or by doing proper maintenance. Since each of the equipments of the electrical power system is very costly so it is almost impossible to redesign the whole system. Hence maintenance is the only procedure to improve the reliability of the electrical system.

Electrical power distribution system consists of a very large no of equipments. So it is not cost effective to do maintenance on all the equipments of the distribution system. Many preventive maintenance techniques are done to reduce the power interruption of the system. RCM is the process of doing the preventive as well as corrective maintenance on the important equipments only which have more impact on the interruption of electrical power supply.

The impact of the equipments of the electrical power system on the interruption of power supply is done with the help of the electrical system reliability indices. These indices are mainly depends on the frequency of occurrence of the interruption and the duration of occurrence of the interruption.

Assam Electricity Regulatory Commission (AERC) has defined and customized indices to quantify the service reliability. The indices AERC is using are listed below.

CAIFI: Customer Average Interruption Frequency Index, which indicates how frequent the average customer experiences a sustained interruption over a predefined period of time and is calculated in interruption/year.

CAIDI: Customer Average Interruption Duration Index, which indicates the duration of the total interruption for the average customer during a predefined period of time and is calculated in minutes/year.

II. Reliability Centered Maintenance (RCM)

RCM method used here consisting of the following steps-

Step1: System selection and data collection from the selected distribution substation for RCM.

System is selected for reliability improvement is based on the statistical data of power interruption. The data is analyzed for the impact of the each equipment to the respective affected customers. The data mainly comprises of date and time of interruption, duration of interruption, causes of interruption and the number of affected customer for each interruption.

Step2: System boundary definition

System boundary is defined to prevent the repetition of the same equipment in nearby area. For defining the system boundary of different system single line diagram is used to divide the system to different zone.

Step3: Selection of the problematic equipment/component

The proper equipment is selected for RCM from the failure rate of each of the equipment of a zone. This can be done with the help of the reliability indices of the system.

Step4: failure mode and method analysis

This analysis uses the relationship between the severity and the frequency of the failure of the equipment to select the proper PM for the continuity of supply in a cost optimization way. Unnecessary PM methods are eliminated to reduce cost of maintaining the continuity of supply. Thus more analysis is done in RCM to maintain the important equipment which has more impact on the continuity of power supply. This enhances the cost optimization procedure by eliminating the maintenance procedure which uses PM for each equipment of the system.

Step5: Set up of new maintenance table Depending upon the RCM method, new maintenance table is set up which include only the important one. This table presents an overview of the maintenance activities related to reliability improvement program.

Step 6: Calculation of failure rate of the equipments with different maintenance techniques.

Equipment failure rate (λ) is defined as the number of interruption per year. As the failure rate decreases the life period of the equipment increases.

Step7: Evaluation of new improved reliability indices.

The main aim of RCM is to lessen the no of interruption of the power supply after correcting the proper maintenance for the system.

$$CAIFI=\frac{\Sigma(I*K)}{N} \qquad (1)$$

Where,

I = Number of interruptions exceeding 10 minutes at a time for the voltage class.

K= Number of consumers whose power supply remained off as a result of such interruptions.

N = Total number of consumers in service at the beginning of the year having that class of voltage supply.

$$CAIDI=\frac{\Sigma(P*K)}{N} \qquad (2)$$

Where,

P = Duration of interruptions exceeding 10 minutes at a time for the voltage class.

K= Number of consumers whose power supply remained off as a result of such interruptions.

N = Total number of consumers in service at the beginning of the year having that class of voltage supply.

III. CASE STUDY: RCM AT BOKAKHAT 33/11KV DISTRIBUTION SUBSTATION

In Bokakhat 33/11KV substation, there are two distribution sub-stations. One is at Bokakhat town and other one is at Kohora. There are seven 11KV feeders supplying the customers. Bokakhat sub-station consists of two 5MVA 33/11KV step down transformers. Each of these transformers has two feeders and 394 distribution circuits consisting of distribution transformer of different ratings.

The single line diagram of the substation is shown below

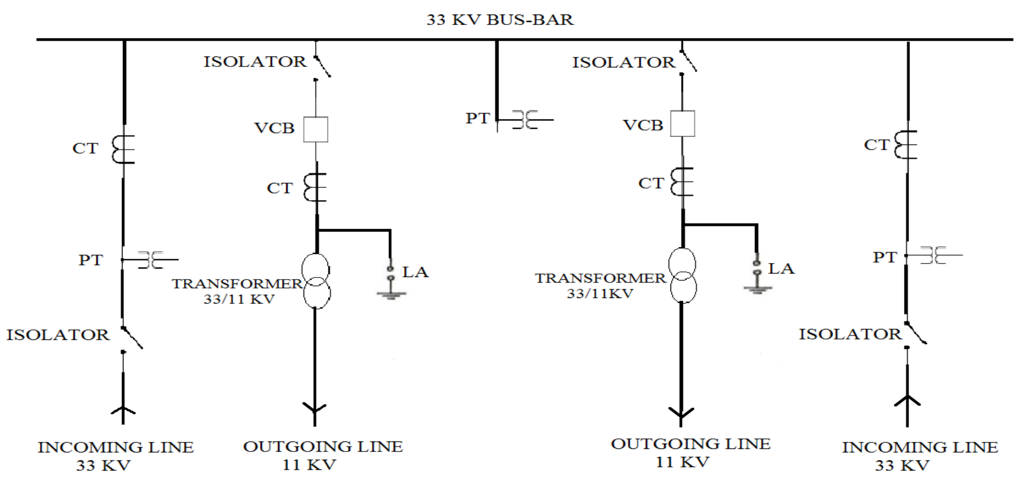

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Fig 1: Single line diagram of the sub-station

Table I: Feeder details of the substation

Name of 11KV feeder	Total length of the feeder	No of distribution transformer in the feeder	Total MVA in feeder	Total no of consumers	Total connected load
	KM	Nos.	KVA	Nos.	kW
BOKAKHAT	8	32	2.21	3319	3630
BORJURI	52	79	3.94	3385	4507
KAKOCHANG	54	86	3.91	3592	4284
EKORAJAN	59	88	6.15	4533	7992
TOURIST	6	14	1.06	621	1421
KAZIRANGA	25	68	0.85	2327	1966
HATHIKHULI	15	28	0.96	1264	2024
TOTAL	219	395	----	19041	25824

Based on the quantitative information from the single line diagram and the data of failure rate of each of the equipments, it is found that the causes of failure of these units are due to different equipment failure due to lake of maintenance and environmental cause.

Line breakdown occurs mainly due to

- Line insulator injury,
- Looseness of joints,
- High tension of the conductors,
- Trees, car crash etc.

And the failure of distribution transformer is due to

- Leakage of oil,
- Loose connection of bushing,
- Degrades of transformer oil quality due to heating up of transformer
- Improper earthing connection, etc.

Depending on the power interruption data the reliability indices CAIFI and CAIDI for two years are calculated in the below table.

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Table II (a). Calculation of CAIFI before PM

STANDARD OF PERFORMANCE REPORT FOR THE BOKAKHAT 33/11 KV SUB-STATION			MONTH :FEB 2016-17	
CONSUMERS AVERAGE INTERRUPTION FREQUENCY INDEX			$CAIFI=\frac{\Sigma(I*K)}{N}$	
NO OF CONSUMERS IN ALL THE FEEDERS N=19601				
NAME OF 11KV FEEDER	NO OF INTERRUPTION(I)	NO OF AFFECTED CUSTOMERS(K)	I*K	CAIFI
BOKAKHAT	210	3447	723870	336.246467
BORJURI	413	4028	1663564	
KAKOCHANG	377	3098	1167946	
EKORAJAN	428	5332	2282096	
KAZIRANGA	241	1879	452839	
HATIKHULI	256	1085	277760	
TOURIST	31	732	22692	
TOTAL	1956	19601	6590767	

Table II(b). Calculation of CAIDI before PM

STANDARD OF PERFORMANCE REPORT FOR THE BOKAKHAT 33/11 KV SUB-STATION			MONTH :FEB 2016-17	
CONSUMERS AVERAGE INTERRUPTION DURATION INDEX			$CAIDI=\frac{\Sigma(P*K)}{N}$	
NO OF CONSUMERS IN ALL THE FEEDERS N=19601				
NAME OF 11KV FEEDER	DURATION OF INTERRUPTION IN MINUTES (P)	NO OF AFFECTED CUSTOMERS(K)	P*K	CAIDI
BOKAKHAT	2104	3447	7252488	3367.989184
BORJURI	4139	4028	16671892	
KAKOCHANG	3776	3098	11698048	
EKORAJAN	4284	5332	22842288	
KAZIRANGA	2413	1879	4534027	
HATIKHULI	2569	1085	2787365	
TOURIST	314	732	229848	
TOTAL	19599	19601	66015956	

After doing some preventive maintenance the new indices are calculated for the year 2017-18 as follows

Table III (a). Calculation of CAIFI after PM

STANDARD OF PERFORMANCE REPORT FOR THE BOKAKHAT 33/11 KV SUB-STATION				MONTH :NOV 2017-18
CONSUMERS AVERAGE INTERRUPTION FREQUENCY INDEX				CAIFI=$\frac{\Sigma(I*K)}{N}$
NO OF CONSUMERS IN ALL THE FEEDERS N=19601				
NAME OF 11KV FEEDER	NO OF INTERRUPTION(I)	NO OF AFFECTED CUSTOMERS(K)	I*K	CAIFI
BOKAKHAT	57	3447	196479	62.53737
BORJURI	81	4028	326268	
KAKOCHANG	63	3098	195174	
EKORAJAN	75	5332	3999900	
KAZIRANGA	43	1879	80797	
HATIKHULI	21	1085	22785	
TOURIST	6	732	4392	
TOTAL	346	19601	4825795	

Table III (b): Calculation of CAIDI after PM

STANDARD OF PERFORMANCE REPORT FOR THE BOKAKHAT 33/11 KV SUB-STATION				MONTH :NOV 2017-18
CONSUMERS AVERAGE INTERRUPTION DURATION INDEX				CAIDI=$\frac{\Sigma(P*K)}{N}$
NO OF CONSUMERS IN ALL THE FEEDERS N=19601				
NAME OF 11KV FEEDER	DURATION OF INTERRUPTION IN MINUTES(I)	NO OF AFFECTED CUSTOMERS(K)	P*K	CAIDI
BOKAKHAT	579	3447	1995813	641.2412122
BORJURI	837	4028	3371436	
KAKOCHANG	635	3098	1967230	
EKORAJAN	753	5332	4014996	
KAZIRANGA	480	1879	901920	
HATIKHULI	234	1085	253890	
TOURIST	87	732	63684	
TOTAL	3605	19601	12568969	

From the above table we have seen that after doing some preventive maintenance methods the failure rate of different distribution system components become less.

As we know that after doing maintenance on different units, its operating condition becomes good. So the failure rate of the different units such as LT lines, service lines, distribution transformers become less in 2017-2018 than 2016-2017. Calculated values of the reliability indices, CAIFI and CAIDI show that the reliability of the distribution system has improved.

Since it is not a easy way to do maintenance on all the equipments in the distribution system because in the selected system there are 394 distribution transformer, a large no of protective device and almost 267 km of feeder. Due to this large no of electrical equipments, preventive maintenance cannot be done on all the equipments to improve reliability.

To overcome these problems, RCM is a very beneficial way to do maintenance on these type of systems. RCM deals with the main or the important equipments which are mainly responsible for the frequent interruption of power.

From the above Table II and Table III we have seen that among the seven feeders, Bokakhat, Borjuri, Ekorajan and Kakochung are more problematic feeders. So RCM selects these feeders for maintenance.

At first we consider the Bokakhat feeder for detailed study of the interruption data. This feeder consisting of 32 distribution transformers, which are of rating 250 KVA, 100 KVA, 63 KVA, 25 KVA and16 KVA. The length of the feeder is 8 km supplying 3316 customers and no of connected load is 3630 kW.

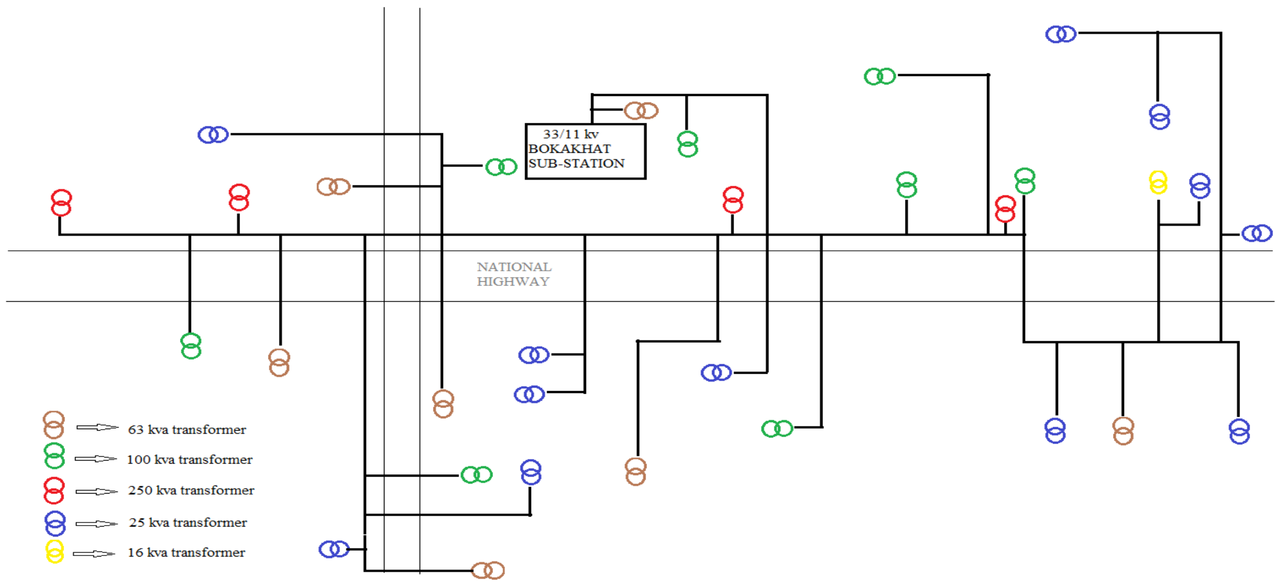

Fig 2: Single line diagram of the Bokakhat feeder

The operation number of protection devices is 57, which can be classified into trip to lockout for 43 events and trip to reclose for 14 events. The cause is known for 44 events and unknown for 13 events. Among these 21 events from equipment failure, 13 events from trees, 6 events from animals, 2 events from natural disaster and 1 event from car crash.

The most of equipment failures are insulator flashover and damage to drop-out fuse cutout. The faults caused by animal such as birds and snakes are found mostly at drop-out fuse, transformer bushing and bared conductor as incoming lead of a transformer.

Failure mode and critical impact is analyzed from the relationship between severity of impact and frequency of events, and is used to specify appropriate PM with cost effectiveness. RCM will perform maintenance only on important equipment that supports system main function, i.e. continuity of supply. It is different from the old way that maintains and focuses on all equipment to be in good condition.

Correction of power outage and maintenance activities

- From power interruption data and cost of maintenance activities, a way to improve and maintain the system can be established. The critical failure modes are found to be caused by equipment, animal and trees.
- Power interruptions from equipment failure can possibly cause a wide outage area and affect a large number of customers. Several factors influence equipment failure such as its quality and working condition. Maintenance activities that can help reduce such a failure are inspection and PM activity, e.g. system patrolling, hot spot checking. Nevertheless, it is important to use high quality equipment by considering its working condition and related standard.
- Preventing power outage caused by animal is a difficult task because of its nature and unpredictable behavior. In this case, inspection activity may not be useful. However, protection and reduction in number of failure can be achieved through the use animal guard and insulated conductor.
- The power outage from trees can be directly cut off by tree trimming activity. Additionally, tree trimming to those trees under the line can also reduce the number of outage caused by animal.

RCM is done on this feeder depending upon the severity and frequency of interruption. Based on the causes of failure and its impact on the continuity of power supply, if RCM is done on the feeder then the no of power interruption is reduced to maximum extend. Table below shows comparative study between different maintenance strategies.

After considering these preventing maintenances, the failures due to the above cause are eliminated. Then similarly doing the same procedure for the other three selected feeder for RCM, the new reliability indices for the whole system are calculated and these are shown below

Table IV (a). Calculation of CAIFI after RCM

STANDARD OF PERFORMANCE REPORT FOR THE BOKAKHAT 33/11 KV SUB-STATION				RCM
CONSUMERS AVERAGE INTERRUPTION FREQUENCY INDEX				CAIFI= $\frac{\Sigma(P*K)}{N}$
NO OF CONSUMERS IN ALL THE FEEDERS N=19601				
NAME OF 11KV FEEDER	NO OF INTERRUPTION(I)	NO OF AFFECTED CUSTOMERS(K)	I*K	CAIFI
BOKAKHAT	19	3447	65493	24.51
BORJURI	27	4028	108756	
KAKOCHANG	21	3098	65058	
EKORAJAN	25	5332	133300	
KAZIRANGA	43	1879	80797	
HATIKHULI	21	1085	22785	
TOURIST	6	732	4392	
TOTAL	162	19601	480452	

Table IV (b): Calculation of CAIDI after

STANDARD OF PERFORMANCE REPORT FOR THE BOKAKHAT 33/11 KV SUB-STATION				RCM
CONSUMERS AVERAGE INTERRUPTION DURATION INDEX				CAIDI= $\frac{\Sigma(P*K)}{N}$
NO OF CONSUMERS IN ALL THE FEEDERS N=19601				
NAME OF 11KV FEEDER	DURATION OF INTERRUPTION IN MINUTES(I)	NO OF AFFECTED CUSTOMERS(K)	P*K	CAIDI
BOKAKHAT	213	3447	734211	286.5349
BORJURI	316	4028	1272848	
KAKOCHANG	245	3098	759010	
EKORAJAN	306	5332	1631592	
KAZIRANGA	480	1879	901920	
HATIKHULI	234	1085	253890	
TOURIST	87	732	62901	
TOTAL	1881	19601	5616372	

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IV. SIMULATIONS AND RESULTS

MATLAB code is used to interfacing the practical data to analyze RCM method with the other maintenance techniques. This is done by using different reliability indices to compare the improvement of the reliability of the power supply of the system.

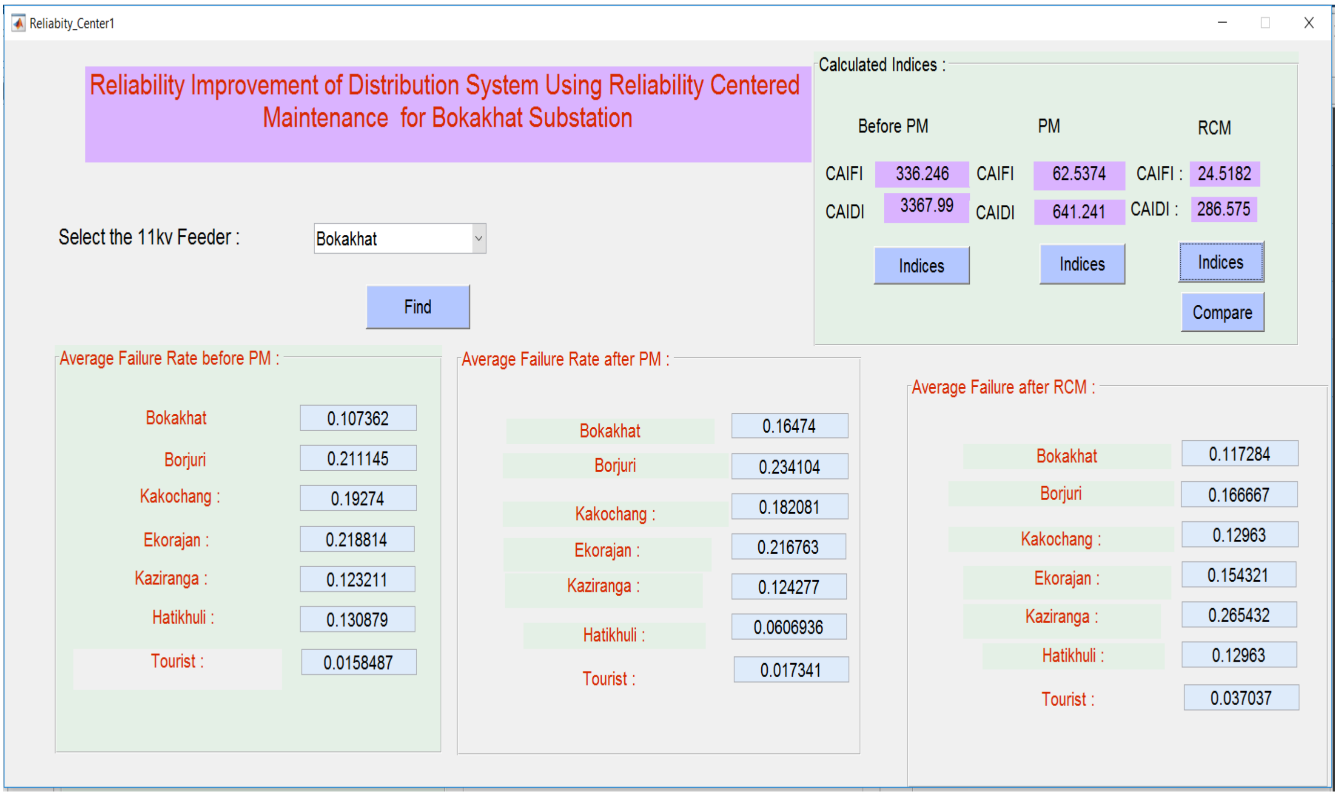

Fig 3: Calculations of different reliability indices and failure rate of all the feeders of the sub-station

From the above fig it is seen that the reliability indices CAIFI and CAIDI are calculated for different maintenance techniques. But among all these techniques RCM method is the optimum method to improve the reliability. The indices decrease to a large extent in case of RCM which is the desirable condition for reliability improvement of any system. The figure below shows the variation of reliability indices with different maintenance techniques.

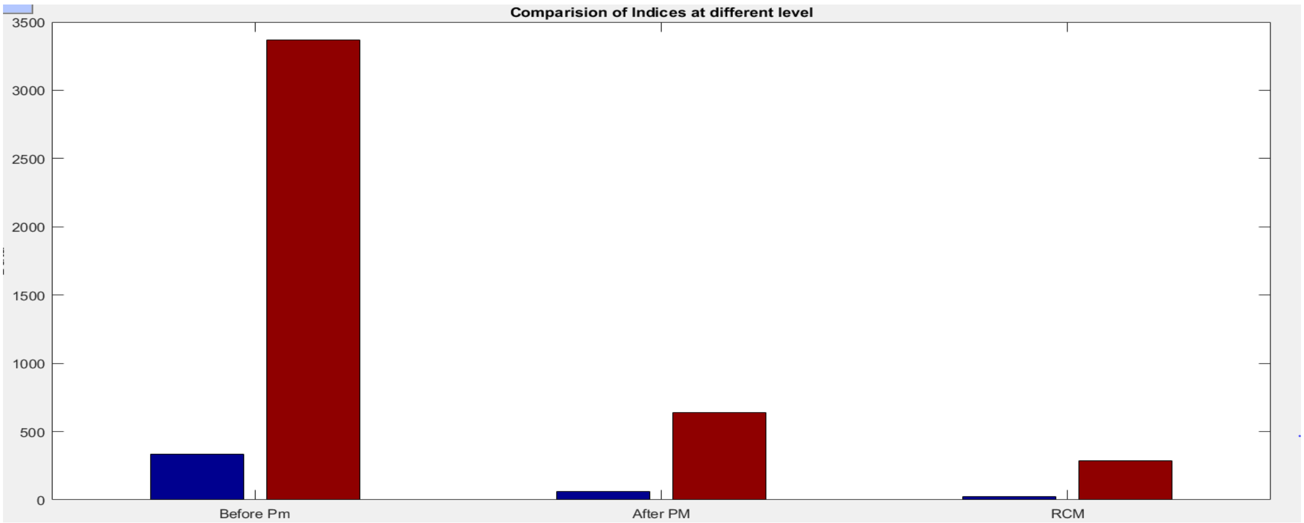

Fig 4: Variation of the reliability indices after different maintenance methods

V. Conclusion

The application of RCM for reliability improvement on distribution system helps utility arrange and prioritize the importance of maintenance activities cost effectively. The method controls and selects the most critical problems and applies the best activities to solve the problem. In this way, utility resource are optimized and utilized effectively. As a result, utility can select appropriate maintenance activity that is best match for its condition and result in high customer satisfaction and service quality.

From the analysis of power interruption data, is clear preventive maintenance gives a reliable power supply to the consumers. But it is impossible to do preventive maintenance for all the equipments of the distribution system. By finding the important equipment which is mainly responsible for the frequent interruption of power supply using reliability centered maintenance technique is a beneficial way of improving the reliability of the distribution system.

Since maintenance of any equipments increases the life span of the equipment. So by using proper maintenance strategy equipments life span can also be increased which is an another benefit for the power suppliers.

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