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Dr. Ashok Kumar Tiwari
General Manager,
MPPKVVCL, Jabalpur,
Madhya Pradesh, India

Correspondence
Dr. Ashok Kumar Tiwari
General Manager,
MPPKVVCL, Jabalpur,
Madhya Pradesh, India

Reliability centered maintenance practices using line ranger network in power distribution

Dr. Ashok Kumar Tiwari

Abstract
In the current context, it is essential for distribution utilities to ensure uninterrupted power supply to their customers. The primary objective is to provide a consistent and reliable service while prioritizing safety. This involves a range of activities such as planning, coordination, analysis, integration, and effective communication, as well as condition monitoring and tracking.
To enhance safety culture and achieve operational excellence, we are implementing Reliability Centered Maintenance (RCM) practices. RCM aims to optimize reliability and costs by utilizing tools and techniques rooted in reliability-centered principles, supported by data and analytics. The emphasis is on prioritizing reliability over mere availability, while keeping costs optimized.
It is important to note that distribution reliability significantly impacts customer satisfaction and has a direct influence on electricity costs. By implementing RCM and focusing on reliability, we aim to improve workers' confidence and morale, enhance productivity, increase operational efficiency, achieve better safety outcomes, and reduce overall risk levels. This paper presents benefits of RCM with application of line ranger in maintenance of power distribution system.

Keywords: RCM, RCA, FMEA, MTBF, FMEA, Line Ranger

Introduction

Introduction to RCM Philosophy

Reliability, in the context of equipment performance, refers to its ability to consistently fulfill its intended function at the designated time and in the expected manner. Achieving reliability involves utilizing dynamic Root Cause Analyses (RCAs), Failure Modes and Effects Analyses (FMEAs), and system analysis techniques. These methods help identify and address potential issues that could affect the equipment's performance.

A crucial component of Reliability Centered Maintenance (RCM) is the utilization of advanced data analytics. By harnessing the power of data analytics, organizations can optimize both reliability and cost aspects of their maintenance strategies. Analyzing large volumes of data allows for the identification of patterns, trends, and insights that can guide decision-making and improve overall reliability.

By integrating advanced data analytics into RCM practices, organizations can make informed decisions regarding maintenance scheduling, parts replacement, and asset management. This proactive approach helps prevent failures, reduce downtime, enhance equipment performance, and ultimately optimize both reliability and cost factors.

Objectives and background

The primary goal of Reliability Centered Maintenance (RCM) is to ensure that equipment performs according to user expectations, within the context of operating conditions, while minimizing the consequences of failure. RCM aims to optimize maintenance plans, predict equipment failure patterns with the appropriate maintenance approach, optimize life cycle costs, and ensure asset health.

Incorporating condition-based monitoring practices is crucial for early diagnosis and prevention of equipment breakdowns. These practices include utilizing tablets for conducting routes (rounds) instead of traditional checklists, employing ultrasonic testing, and implementing thermal vision scanning.

In the past, maintenance practices predominantly followed a reactive approach, relying on static Root Cause Analysis (RCAs) to address issues. These practices were primarily guided by O&M (Operations and Maintenance) expertise and past experiences. The approach involved capturing historical data through a combination of time-based and condition-based methods, but it had limited utility. Real-time data monitoring and compliance through information technology (IT) were also utilized.

Triggers for RCM implementation
1. Stress on Discom profitability due to external factors
2. New performance benchmarks are being created every day
3. The complex set of assets with pockets of excellence – "mini firms within one organization
4. "Set practices are the best practices " mind-set
5. "People have driven rather than system driven"
6. To avoid the fire-fighter mode of business operations.
7. To identify the presence of "hidden" costs and value
8. To align inconsistencies between "intent and performance"
9. Reliability-cantered maintenance has a proactive approach with dynamic RCCAs, FMEAs, and system analysis. RCM is using analytics-driven time & condition-based maintenance. It uses historical data for analytics and prediction. Real-time data with analytics helps in identifying interventions for monitoring equipment health and IT-driven maintenance strategy.

RCM focuses on reliability instead of availability with optimized cost. Key elements needed to achieve the end state of RCM and Overall maintenance strategy stabilized across sites -
- High levels of availability
- In-depth understanding of assets
- Improved data capture to aid analytics
- Strong team in place, with know-How to execute

Area	Conventional Maintenance	RCM
Objective	Maximize availability, mostly through routine PM and CBM, as specified by OEM manuals.	Equip. performance the way/when users want, in the context of op. conditions, by reducing consequences of failure
Formulation of mainte4nance plans	Static: lim. Change with age/health Based on OEM/ User experience Analysis based on historical data	Dynamic opt. between PM, CBM, CM Driven by classification, FMEA, analyses Zero based approach
Level of optimization	Equipment level	Equipment and system level
Lifecycle costing	Maintenance activities give limited consideration to cost of maintenance vs cost of failure	Cost-benefit analysis done at an activity level, taking into consideration equipment health and assumed residual life
Analytics capability required	Limited requirement for analytics (ERP is sufficient)	Staff to have high skill in analytics (enabled through RCM IT solutions, in addition to ERP)

Scope
Various approaches to RCM implementations are as follows:
Codification and classification: The revised approach facilitates the accurate identification of equipment defects, enables consistent failure analysis, and ensures proper cost capture. The standardization steps for codification and classification are as follows:
1. Creation of functionality-based functional locations: Functional locations are established based on specific functionalities or operational areas.
2. Identification of equipment within a functional location: Within each functional location, equipment items are identified and associated with their respective functionalities.
3. Equipment hierarchy definition: A hierarchical structure is created to define the relationships and dependencies between equipment items, establishing a clear hierarchy.
4. Horizontal and vertical extensions: The hierarchy is expanded horizontally by adding more equipment items within each functional location, as well as vertically by including sub-equipment or component levels within the hierarchy.

By implementing these codification and classification steps, organizations can effectively categorize and organize equipment, enabling streamlined maintenance processes, accurate failure analysis, and improved cost management.

Why were codification and classification required?
1. Removal of non-core defects from main equipment.
2. Analysis of defects
3. Defect aggregation at the right equipment and functional location level to facilitate comparison of a similar system.
4. Automatic capture of cost and failure data.

Key elements considered for classification are the consequence of failure. The repair cost of failure and redundancy and detection.
Classification helps in deciding the priority of proactive maintenance of class equipment for which impact is more than C class equipment which may not affect the much during failure. FMEA: Failure mode and effect analysis is a tool to identify and quantify the existing risk of the system. This tool helps the user to understand the potential failure modes and the impacts. FMEA helps to improve reliability by proactively identifying potential failures and mitigating them by taking appropriate action.

Benefits: Helps in improving equipment reliability in long term.
1. Increase in time between two failures: MTBF
2. Path to zero forced outage
3. Standardize failure and effect data capturing linked with the right equipment, object, and the root cause.
4. Optimize maintenance efforts based on the potential impact of failure modes.
5. Maintenance optimization:

Maintenance optimization is the key outcome expected from the entire RCM activities. With the foundation of codification, classification (equipment criticality), and FMEA (RPN no., action items, cost, etc.) being ready, maintenance strategy for equipment can be optimized

Key activities of maintenance optimization
1. Define custom maintenance strategy for critical equipment by exploring the right mix of CM, PM, and CbM.
2. Introducing new action item to mitigate high-risk failure modes.

3. Rationalization of existing task list frequencies points to transition from Pm to CBM.
4. Effort estimation got corrective/breakdown activities for future contract negotiations.

In order to define the maintenance strategy, a 3 steps structured approach has been undertaken:

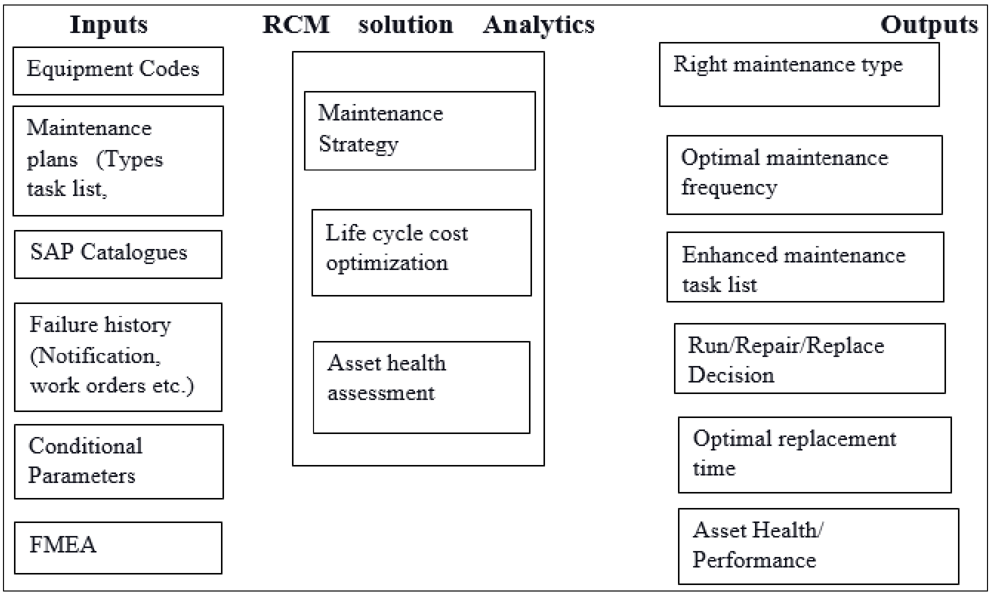
1. **Dominant maintenance strategy:** Based on equipment criticality (classification) and the cost involved in maintaining an equipment, we can arrive at the recommended/ dominant maintenance strategy.
2. **If an equipment is class A:** It will in most probability require a proactive action, as a failure of such equipment will have huge implications.
3. If an equipment is class C, cost of maintenance vs cost of failure, and decide the right maintenance type for such equipment.
4. **Action item implementation:** With inputs of new action items from FMEA, a thorough cost-benefit analysis can recommend which action items are cost-beneficial for adoption, or whether they should be dropped.
5. **Task list rationalization:** In addition to new tasks coming out of FMEA, there might be q requirement to remove some law-impact tasks existing in the current task list. Hence, prioritization of tasks for improved reliability by adding new tasks and removal of low-impact tasks.

Measurement points are to be added, wherever possible to enable a transition from PM to CBM.
Based on historical failures, the solution tries to plot them on a curve. (MTBF vs time), and then based on the pattern a recommended strategy of PM/CBM/CM is provided as the output.

Cost-based optimization

Trade between failure cost and maintenance cost is plotted on a cost vs. frequency of maintenance scale. The solution plots the curve for different maintenance frequencies. The point where some failure and maintenance cost is minimum is recommended as the optimal frequency of maintenance.
Desired strategy optimization of RCM solution necessitates accuracy and comprehensiveness of data. Data improvements across master and transactional data are keys to RCM success.

Roles of data in RCM



Data quality gap areas

Notification Data	Incomplete/ inaccurate capture of failure history through notifications Effect: Inaccurate, maintenance optimization, MTTR, MTBF etc.
SAP Catalogues	Non- standardized, non-comprehensive object/failure/cause catalogues Effect: Inaccurate capture of failure history during notification closure
Maintenance plan and task list	Non-Comprehensive task list and missing/inadequate measuring points for critical equipment Effect: Inadequate data capture from field, with insufficient quality of work
Bill of material	Incomplete equipment-BOM mapping, and inaccurate BOM details Effect: Inaccurate material management planning

1. Maintenance shift from availability to reliability.
2. Analysis of IT solutions for maintenance.
3. Adoption of digital tools for productivity enhancement.
4. Culture alignment: Openness, innovation, achievement.
5. Capability & Skills enhancement of O&M organization.
6. Cross-organization communications management.
7. Adoption of digital tools for productivity enhancement.
8. Tangible value capture across assets.
9. Better asset performance.
10. Improved accuracy in maintenance planning.
11. Real-time actions to improve reliability.
12. Quicker decision making.

The challenge to Indian Discoms

Discoms AT&C power losses continue to stay stubbornly above the targets. Set by UDAY and the industry' despite years of focussed efforts. Even more concerning, improvements secured are not always kept. per UDAY, as of august 2021 average AT& C losses across. India was 22%.

An Expensive problem In India, there are about

74 Discoms
7.5 million Circuit KM in use.
2.85 trillion KWh is generated per year.
12.8 Lakh Crores ($183B) annual tariff paid.
3.8 Lakh Crores ($ 55B) of tariff not realized.

This is enough to financially swing most discoms from a profit to a loss. The government must absorb the rest. Even with the UDAY plan covering 15% of losses, there is still excess to be absorbed.

Both Government and banks suffer. Currently, about 44% of India's discom bank loans are nonperforming. This figure quantifies to Rs 70,000 crores ($10B) in bad Loans! Clearly, there can be high value to the country at large in reliving this suffering.

Enter the line ranger (LR) network

The Line Ranger network integrates online sensors and AI software to facilitate real-time hotline maintenance. It detects, tracks, and traces losses on live power lines, providing immediate alerts and detailed information. This advanced system identifies and distinguishes between technical and commercial losses, offering analytics to help understand the specific situation and providing actionable insights.

The Line Ranger network is capable of detecting abnormal usage, line imbalances, and various sources of losses such as degrading elements, phase imbalances, load imbalances, tapping/theft, and metering problems. Additionally, it predicts the remaining lifetimes of power lines by sensing degradation, I^2R loss, and estimating the expected time to failure.

By leveraging the Line Ranger network, utilities can improve their preventive maintenance planning. It enables them to allocate resources more efficiently, potentially saving up to 60% of the maintenance and repair budget. Moreover, this technology allows for increased current flow and revenue generation while maintaining reliable power distribution.

Patented platform technology

The line ranger network combines harmonic distortion sensing techniques, intelligent algorithms, and mathematical models specifically for power lines to identify, track and trace the losses and predict power line health. Patents are issued and additional patents are pending.

Line Ranger (LR) Network Description

The line ranger network is an adaptable artificial intelligent system for use on any distribution (or transmission) line. It measures key characteristics in real-time. The software establishes a baseline.

Performance and identifies "abnormal" power loss. It can also separate technical vs commercial losses and can project the remaining lifetime of lines.

The software also provides analytics and creates graphs and charts that "tell the story" of line status and performance and establish permanent records.

Data stream and communication

The LR network communicates through a simple 32- bit data stream as shown below. It measures the primary characteristics shown and calculates others as needed.

Data Stream: 8 bit – location (GPS) & time stamp
4 bit – Voltage
4 bit – Current
4 bit – Temperature
4 bit – Capacitance
4 bit – inductance
4 bit – phase parameter
Total – 32 bits

The devices are interlinked in a serial path using standard communication protocols. The specific protocol, GSM, RF, etc. can be chosen by the user. The devices are connected to each other, Then to remote collection midpoints as needed, and back to a principal data collection center. At the collection center, the data is analysed, reported and stored.

Reports can be anything from real times status to longer-term trends and analysis. Alerts and alarms can be set, including text or email alerts to key leadership and personnel for immediate action.

Unique, Easy-To-Use Human interface

The human interface is clear and simple to use, requiring no more expertise than Google maps. In fact, the lines are overlaid on google earth for context. From there the user sees system status, issues, and data online, drilling down to the underlying details as desired. All viewing is permission based. Real-time and historical status as well as analytics are available.

Easy to install on Live Lines

The LR devices can be put on and taken off the lines with a hot stick if the lines are live. This can be done from the ground or by a ladder or a lift. The units clamped onto the line in a "clamshell" Fashion.

Data Examples

Below are some examples of actual data, highlighting certain characteristics.

All characteristics Time Synchronized

Examples of actual data, highlighting certain characteristics shows that in this case, The frequency, Power factor, current, and voltage are all shown together. Not as an example, this line tripped three times and the characteristics of all aspects can be seen in synchrony.

Interconnect Health

Here are some examples of measuring line health. Note that the degradation factor of a new line is 1.0 and the typical resistivity of a line in the US is 85 micro table are heavily degraded. This multiplies technical power loss. The I^2R losses can be calculated. Also, the higher degradation factor means the line is closer to failure.

Predicting Lime Life

Knowing the diameter and composition of the line, The Line Ranger can create a lifetime graph and status similar to the one shown. It will provide an actual range of remaining life, in days, weeks, months, or years.

Instabilities

Here is an example of line instabilities at the three different phases of a line as indicated by the blue, red, and green below. Generally caused by arcing across junctions, creating frequency surges. High-frequency instabilities may trigger system level instability which can lead to sag, surge, degradation of power factor, or tripping.

Unexplained Commercial Loss

Below is an example of commercial loss. From the substation to the first “T”, no known customers. Yet an average 15 A at 33 KV lost. Theft?

Line imbalance induced by customer

Below are some examples of actual data, highlighting certain characteristics. The imbalanced legs lead to loss. They should be within 1% if in balance. In this case as much as 20% loss. Likely caused by customer events. This could also be due to theft on 29BR leg. Imbalances and transients induced by rapid current changes have a detrimental effect on the health and stability of the system as a whole.

Frequency imbalance

Below is an example of frequency imbalance. Generally caused by arcing across junctions, creating frequency surges. Arcing from a loose connection, Wind sway, etc. high-frequency instabilities may trigger system level instability which can lead to sag, Surge, Degradation of power factor, or tripping.

Conclusion

The adoption of RCM offers several benefits, including a shift from availability-focused maintenance to reliability-focused maintenance, the analysis of IT solutions for maintenance, adoption of digital tools for productivity enhancement, alignment of organizational culture towards openness, innovation, and achievement, enhancement of capability and skills within the O&M organization, improved cross-organizational communication, tangible value capture across assets, better asset performance, improved accuracy in maintenance planning, real-time actions to improve reliability, and quicker decision-making. As power distribution companies (discoms) strive to reduce losses, a novel solution has emerged for detecting and addressing problems more efficiently. The Line Ranger Network, a recently patented innovation, offers a hotline for problem detection and maintenance. By leveraging artificial intelligence (AI) and sensors, this system provides real-time data to predict and identify issues, generating alerts and maintaining a permanent record. Installation and usage are straightforward, and the return on investment can be achieved rapidly. With this advancement, problems can now be identified and rectified on live power lines, enabling real-time verification of corrections.

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