The importance of maintenance activities and negative contributing factors faced by electricity distribution maintenance industry

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The main objective of maintenance is to ensure equipment reliability, to extent its life cycle and to maximize equipment availability in order to achieve and deliver the acceptable quality of service or product. Failing to comply with scheduled and prescribed maintenance activities might or will be resulted to disruptive, inconvenient, wasteful and expensive circumstances. The purpose of this presentation is to highlight the importance of maintenance and negative contributing factors faced by electrical distribution maintenance industry, and it also present the analysis of preventive and corrective maintenance. The analysis is based from theoretical and case studies conducted from the electrical distribution industry.

Introduction

Maintenance is an activity involved in maintaining a system or equipment to be in a good working order, to improve the reliability and sustainability of the system or equipment and to extent its life expectancy.

In electricity distribution maintenance industry we are compelled by certain legislations and guidelines [1, 3, 3, 4, 5], manufacturer guidelines, and maintenance strategies and philosophies to conduct maintenance in specific mode.

Maintenance activities in most instances are not carried out as planned due to unplanned and unforeseen circumstances within the electricity distribution industry; and we then embarked on corrective maintenance only, and that resulted to not meeting the scheduled activities of preventive maintenance.

The eventual ageing of the electrical network, the extent damage experienced, conduction of repeatable repairs in the same areas and lack of maintenance leads to deterioration of the electricity distribution network.

Types of maintenance

![Preventive and corrective maintenance](image)

Fig. 1: Preventive and corrective maintenance.

Fig. 1 indicates the commonly most effective maintenance types that incorporate all maintenance activities in order to keep the equipment or system in a good working order being reliable and sustainable [6,7].

Preventive maintenance

It is the maintenance that is performed before a failure occurs to preserve a system in satisfactory condition; it involves performing routine inspections and servicing. It is categorized by time-based and condition-based maintenance. Time-based maintenance is performed at regular time intervals (e.g. number of tripping); and condition-based maintenance is based on the knowledge of the condition of the equipment from routine or continuous monitoring (systematic inspections, measurements) [6].
Corrective maintenance

It is the maintenance performed after a failure occurs, and it is also categorized by immediate and deferred maintenance. Immediate maintenance is performed immediately as it is being regarded as an emergency; and the deferred maintenance might be scheduled for another period based on the priority of activities.

Models in maintenance

Reliability

Reliability is the probability that a machine or equipment will operate properly without failure for a specified time under stated condition. It is an element that must be considered within the electricity distribution maintenance industry since our systems are composed by a series of interrelated components, of which some are dependent on others; which imply that if one component fails due to whatsoever reasons, then the whole system will fail. So it is very imperative to analyze and assess the equipment reliability at all times.

- Functions used in reliability

<table>
<thead>
<tr>
<th>Function</th>
<th>Symbol</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure density</td>
<td>$f(t)$</td>
<td></td>
</tr>
<tr>
<td>Reliability</td>
<td>$R(t)$</td>
<td></td>
</tr>
<tr>
<td>Unreliability</td>
<td>$F(t)$</td>
<td></td>
</tr>
<tr>
<td>Failure rate</td>
<td>$\Lambda(t)$</td>
<td>Time^{-1}</td>
</tr>
<tr>
<td>Mean time to failure</td>
<td>MTTF</td>
<td>time</td>
</tr>
</tbody>
</table>

Table 1: Reliability functions.

- Example of reliability calculations

\[
R_c = R_a \times R_b \times R_c
\]

\[
\text{Fig. 2: Series relationship.}
\]

Therefore, system reliability will be:

\[
R(t) = R_a + R_b + R_c
\]

(1)

Where:

\[
R(t) = \text{reliability}
\]

\[
R_a = \text{component reliability a}
\]

\[
R_b = \text{component reliability b}
\]

\[
R_c = \text{component reliability c}
\]

Therefore,

\[
R(t) = (R_a)(R_b)(R_c)
\]

\[
R(t) = (0.90)(0.95)(0.88)
\]

\[
R(t) = 0.75, \text{ this calculation denotes the interdependency of the system reliability connected in series in Fig. 2 as 75 \%.}
\]
Fig. 3: Series and parallel relationship.

Therefore, system reliability will be:

$$ R(t) = [Ra + Ra \times (1 - Rd)] \times [Rb + Rb \times (1 - Re)] \times Rc $$

(2)

Where:

- $R(t)$ = reliability
- $Ra$ = component reliability a
- $Rb$ = component reliability b
- $Rc$ = component reliability c
- $Rd$ = component reliability d
- $Re$ = component reliability e

Therefore,

$$ R(t) = [0.89 + 0.89(1 - 0.9)] \times [0.99 + 0.99(1 - 0.95)] \times 0.85 $$

$$ R(t) = 0.87, \text{ and thus the system reliability of figure 3 is 87\%}. $$

Measuring of failures

Failure is a function time, which means that somewhere along the life cycle of the equipment; its reliability will be affected and it will advance to a failure phase. Due to this, planning of maintenance activities becomes a key factor in reducing failure and maintaining the reliability of the equipment or process. This can also be achieved by considering the phenomenon of bathtub [8] curve as indicated on figure 4.

Fig. 4: The bathtub curve.
Bathtub curve indicates likelihood of equipment failures in three stages, whereby stage one is infant mortality failure (wear in zone), stage two being random failures (normal operating zone) and stage three is wear out failures (wear out zone). This phenomenon can assist in measuring and assessing failures of equipments. Although the change in technology could affect certain equipments performance, it still could be advantageous to have a pattern of equipment failures being analyzed and benchmarked for reference and further research purposes.

Maintainability

Maintainability of an item can be defined as the probability that an item can be returned to a specified functional level within a specified period. It must be noted that we can reduce and save the loss experienced due to electrical power failures if we reduce the maintenance down time and being proactive in terms of logistical delay time. However, if we cannot embark on improving our maintainability we will find ourselves faced with litigations, lot of customer complains and negative remarks concerning service delivery.

- **Functions used in maintainability**

\[
m(t) = \left(\exp(-vt)\right) \times \exp(-vt)
\]

\[
M(t) = \left[1 - \exp(-vt)\right]
\]

\[
MTTR = \frac{1}{v}
\]

Where:

- \(m(t)\) = repair density
- \(M(t)\) = maintainability
- \(MTTR\) = mean time to repair
- \(v(t)\) = \(v\) = repair rate

- **Example of maintainability calculation**

If the repair rate for the replacement of mini-substation transformer is constant \(0.08\) min\(^{-1}\), and the replacement duration is 270 min. Determine the maintainability of the mini-substation and the MTTR.

Therefore, the solutions will be:

Constant repair rate, \(v = 0.08\) min\(^{-1}\)

Maintainability,

From Eqn.4, \(M(t) = \left[1 - \exp(-0.08 \times 270)\right] = 1.0\)

\[
MTTR = \frac{1}{v}
\]

From Eqn. 5, \(MTTR = \frac{1}{0.08} = 12.5\) min

The above calculation indicates 12.5 minutes is the mean time to repair the mini-substation transformer.

Availability

It is defined as the probability that an item will, when used under specified conditions, operate satisfactory and effectively. In order to increase the availability of the system, we have to increase the mean time between failures which will mean that the system will remain in operation for longer durations. Another method of increasing the availability of
the system is to speed up the response time during breakdowns and power failures. It is also the most crucial element to consider within electricity distribution maintenance industry because it gives an indication and measurement of the overall performance and service rendered to the customers.

- *Availability can be calculated as follows:*

\[
Ao = \frac{\text{Operating hours}}{\text{Operating hours} + \text{MTTR}}
\]  

(6)

Integration of maintenance activities

The best maintenance approach is the integration of both maintenance types (preventive and corrective); hence the type of business will dictates as to how the integration should be arranged. If the maintenance plans are compiled in such way that they accommodates and satisfies both types; therefore our ends results will fulfill system availability, maintainability and reliability.

Maintenance strategies and philosophies

*Business- Centred Maintenance (BCM)*

This strategy was developed in response to the need for a more cost effective approach towards maintenance, but with a high priority for safety. It analyses the overall objectives of the enterprise and maintenance department; and then the life plan of system is analyzed by considering inputs from top-down and bottom-up.

*Total Productive Maintenance (TPM)*

Total productive maintenance is defined as a system of maintenance covering the entire life span of equipment and involving everyone from top to bottom of an organization. It is focused on total quality management concepts to the practice of preventive maintenance approach; it involves the concepts of reducing variability through employee involvement and excellent maintenance records. This is accomplished through the elimination of all losses and by adopting a zero defect, zero loss and zero failure approach.

*Reliability-Centred Maintenance (RCM)*

Reliability-centred maintenance transforms the relationships between the undertakings which use it, their existing physical assets and the people who operate and maintain those assets. It is an asset-centred approach with an objective of the realization of the inherent reliability of a system, and it enables the system to be put into effective service with great speed, confidence and precision. This is achieved by analyzing failure pattern, the probable failure mode of a component and the severity of the consequence of a failure determines the maintenance effort needed to prevent the failure and maintenance life plan for each component or item of a system.

Electricity distributions maintenance activities

*Preventive maintenance*

Fig. 5 indicate a case study on preventive maintenance conducted at City of Tshwane: Energy and Electricity Division in four distribution operations areas for a ten months period.
As indicated on Fig. 5, distribution area 4 is excelling in terms of meeting its obligations of created or scheduled preventive maintenance activities, and then followed by distribution area 2 and 1 respectively. Although the geographical areas of due restriction are unequal concerning maintenance activities, that does not disqualify the fact that still more effort needs to be devoted in distribution area 3 for compliance, effective maintenance and reliability since its preventive maintenance activities are shocking as is the lowest in all categories.

Fig. 6 indicate the preventive maintenance gap analysis within all distribution areas; distribution area 1 has completed 36% of its preventive maintenance, 64% of created orders are still outstanding which implies that its preventive maintenance performance is behind schedule by 64% and compliance to its schedule maintenance is lagging by 59% [10].

Corrective maintenance

Fig. 7 indicate a case study on corrective maintenance conducted at City of Tshwane: Energy and Electricity Division in four distribution operations areas for a ten months period.
Fig. 7: Corrective maintenance activities.

All corrective maintenance activities on Fig. 7 have been attended and fully completed within all distribution areas, this denotes that all were immediately attended as an emergency activities; and no activities was regarded as deferred maintenance. The overall performance on corrective maintenance is remarkable and it also emphasizes the attention within distribution areas devoted to corrective maintenance. This is the best practice even though it is not advisable to embark on corrective maintenance at all times.

Comparison of preventive and corrective maintenance activities

Fig. 8 indicates the comparison of preventive and corrective maintenance activities based on the conducted case studies.

Fig. 8: Preventive and corrective maintenance analysis.

The best practice range of preventive maintenance is above 80%. This range is not more specific because the type of business dictates the amount of planned work that can be accomplished. As long as is less than 20% is reactive, which means 80% or more is planned and scheduled, and therefore the organization is considered to be in a best practice category [10].

In all four distribution areas as indicated in Fig. 8, corrective maintenance activities conducted exceeds preventive maintenance activities; and that cannot be regarded as a good practice in conducting maintenance.

Compliance graph has been introduced in order to ensure compliance and best practice; as indicated on the graph it means that for distribution area 1 to comply, it has to do 1218 preventive maintenance activities in line with 305 corrective maintenance activities and that will correspond to 80/20% principle of best practice.

In calculation, if:
\[ Tm = P + C \quad (7) \]

\[ Cp = 80\% \times Tm \quad (8) \]

Where:

- \( Tm \) = total maintenance activities
- \( P \) = preventive maintenance activities
- \( C \) = corrective maintenance activities
- \( Cp \) = compliance to best practice

Therefore,

From Eqn. 7, \( Tm = 618 + 905 = 1523 \)

From Eqn. 8, \( Cp = 0.8 \times 1523 = 1218 \); that is the preventive maintenance activities to be completed for compliance to the best practice as indicated in figure 8, and its corrective maintenance will be constituted to 20% \( Tm \) which is 305 activities.

**Maintenance activities producing positive satisfactory results**

No maintenance type can operate autonomously and be rated the best; either being preventive or corrective maintenance, they have to be integrated together to produce positive satisfactory results, and this is the best approach needed towards compliance to the best practices.

**Negative factors affecting maintenance**

**Copper Theft**

One of the factors that is affecting the process of electricity distribution maintenance industry negatively is copper theft, which is also called conductor theft. People who are embarking of this exercise are more interested in copper than any other metals (aluminum, silver, gold, etc.). The planned maintenance activities are compromised and not carried out as planned in some instances due copper theft, as we found ourselves reacting to copper theft incidents.

The impact of copper theft is experienced both internationally and locally; and is gaining momentum every year. The Conroe City Council approved a new ordinance for scrap metal dealers in an effort to combat the theft of copper wiring in the region [11].

Table 2 and Fig. 9 illustrates a case study conducted at City of Tshwane: Energy and Electricity Division on the assessment of captured claims contributing towards maintenance activities; and the study was based on five years consecutively.

<table>
<thead>
<tr>
<th>FINANCIAL YEAR</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 2003 to June 2004</td>
<td>R 6,123,753</td>
</tr>
<tr>
<td>July 2004 to June 2005</td>
<td>R 7,155,137</td>
</tr>
<tr>
<td>July 2005 to June 2006</td>
<td>R 8,846,619</td>
</tr>
<tr>
<td>July 2006 to June 2007</td>
<td>R 30,355,661</td>
</tr>
<tr>
<td>July 2007 to June 2008</td>
<td>R 4,263,628</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>R 56,744,797</strong></td>
</tr>
</tbody>
</table>

*Table 2: Summary of captured claims*
Based on the above captured claims, we experience a radical escalation of incidents in year three by 243%, which clearly indicates the impediment suffered by preventive maintenance activities. The results of the case study send a signal of gearing ourselves to the appropriate gear with regard to copper theft since it deteriorates the network, affect the maintenance activities and also creates lot of inconveniences.

**Copper theft scenario**

If we assume that 100 m of 70 mm² by three wire steel wired armoured (SWA) 11/11 kV copper cable is stolen by the unknown person, and 1 m of copper for the same cable is equals to 9.94 kg, costing R50,00 of bright and shiny copper per kilogram:

Therefore,

\[ CU = m \times \text{kg} \times R \]  

(9)

Where:

- \( CU \) = the price for bright and shiny copper
- \( m \) = meters of stolen copper
- \( \text{kg} \) = kilogram per meters of stolen copper
- \( R \) = amount in rand

From Eqn. 9, \( CU = (100 \times 9.94 \times 50) = 49,700 \), this means that the unknown person will receive R49,700 for the exchange of copper.

**Repair cost scenario**

The repair costs of the same 100 m of 70 mm² by three wire steel wire armoured (SWA) 11/11 kV copper cable is stolen by the unknown person is indicated on table 3.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>CATEGORY</th>
<th>QUANTITY</th>
<th>RATE</th>
<th>UNIT</th>
<th>AMOUNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Artisan</td>
<td>4</td>
<td>100</td>
<td>8</td>
<td>R 3,200</td>
</tr>
<tr>
<td>2</td>
<td>Special Worksmen</td>
<td>2</td>
<td>100</td>
<td>8</td>
<td>R 1,600</td>
</tr>
<tr>
<td>3</td>
<td>Artisan Assistant</td>
<td>4</td>
<td>60</td>
<td>8</td>
<td>R 1,920</td>
</tr>
</tbody>
</table>

**Fig. 9: Captured claims within five year period.**
Table 3: repair costs calculation.

The repair costs (direct costs) that will be incurred is amounted to R56,709; and we have to bear in mind that this does not include other indirect costs (like costs suffered by the client), which might even be twice the repair costs, depending on the nature of damage experienced.

**Budget**

Budget is one of the key elements when it comes to maintenance activities, but you will find that in most instances maintenance budget is given less priority by some of the organizations during budget allocation, instead more entertainment than maintenance. This has got an enormous negative contributing factor towards maintenance activities. It is like having a car without enough money for petrol.

We can equate maintenance activities in simple terms as:

\[
MA \propto \frac{BA}{LP}
\]  

Where:

- \(MA\) = maintenance activities
- \(BA\) = budget allocation
- \(LP\) = less priority

Eqn. 10 illustrates that maintenance activities is directly proportional to budget allocation and inversely proportional to less priority; that signifies that if more budget is allocated, then more maintenance activities will be achieved, but more less priority will be resulted to disruptive, inconvenient, wasteful and expensive circumstances.

Figure 10 indicates a case study on budget allocation versus asset value conducted at City of Tshwane: Energy and Electricity Division in four distribution operations areas for one calendar year.

Fig. 10: budget allocation versus asset value.

As indicated in Fig. 10, budget allocation for distribution area 3 is 0.81% as compared to its asset value. It might be that more budget allocation is planned in the next budget year, but if we focus on the present, then this budget is too low to produce positive maintenance activities results.
One benchmark that is rapidly gaining acceptance divides the total maintenance cost by the estimated replacement value of a plant or facility [10]. Since the best acceptable high value is 5%, and distribution area 3 obtained 0.81%, therefore the difference that will lead to the acceptable value is 4.19%.

In summation, distribution area 3 needs R47,243,995 as compared to the current allocation of R7,644,748 to cater for all maintenance activities and this clearly indicates inadequacy that is faced by electricity distribution maintenance industry.

Therefore the allocation operational budget should be aligned with the complete maintenance plan in order to accommodate all maintenance activities.

**Resources**

Some of the maintenance activities require specialized machinery and equipments to be executed; maintenance personnel should be fully equipped with certain specialized courses for exposure, knowledge and also to acquire necessary skills needed for job; it is extremely imperative that the available machinery and equipments are fully tested, calibrated and healthy for the work. The quantity of employed maintenance personnel must be equivalent to the maintenance activities in order to avoid unnecessary deferred maintenance, overtime and fatigue. The fundamental matter is that the overall shortage of resources has a negative effect to electricity distribution maintenance industry.

**Curbing strategy towards compliance**

All factors that affect electricity distribution maintenance industry negatively should be considered during the compilation of the maintenance plan, and a curbing strategy must be introduced in considering compliance towards the maintenance activities.

**Conclusion and recommendations**

This paper presents the importance of maintenance activities and negative contributing factors faced by electricity distribution maintenance industry; and it is extremely important to integrate preventive and corrective maintenance activities during the compilation of the maintenance plan.

Compliance to planned maintenance activities should be treated as a trend towards maintaining the network in good working order and best practices.

The selling of copper should be properly legislated like gold and platinum; which will in turn be resulted to the reduction of numerous copper theft incidents experienced by electricity distribution maintenance industry and others.

Maintenance budget should be given priority during the budget allocation process in order to ensure conduction of effective maintenance activities as per maintenance plan.

Comprehensive tactical plans to curtail negative contributing factors towards maintenance activities should be formulated and be implemented; as this will serve as an absolute investment towards the industry and will worth the price during the course of time.

**References**


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