RELIABILITY-BASED MAINTENANCE OF ELECTRICAL POWER DISTRIBUTION SYSTEMS: A PANACEA TO ERRATIC POWER SUPPLY IN ABUJA ELECTRICITY DISTRIBUTION COMPANY

By

Istifanus K. Kalat; Raymond, E; Owodunni, S A and Saba, T M

Industrial and Technology Education Department
School of Science and Technology Education
Federal University of Technology Minna
***E-mail:** ikkalat2013@gmail.com*

Abstract

This paper discusses maintenance and maintenance strategies with specific reference to Run-to-Failure maintenance; preventive (scheduled) maintenance; predictive (condition-based) maintenance. It also discussed the need for reliability-based maintenance as well as its intricacies reflecting on ita principles and potential questions. It enumerated the advantages of reliability-based maintenance which include among others: Rapid drop in maintenance cost; drop on downtime; better control on asset management and lifetime expectancy. It was recommended among others that: The strategic management of Electricity Distribution Companies should as a matter of urgency embrace and direct technical staff supervisors to adopt the tenets of reliability-based maintenance as the most efficient maintenance practice;Management of Electricity Distribution Companies should organize capacity building for technical staff supervisors on the effective and efficient implementation of the reliability-based maintenance approach.

Keywords: Maintenance, Reliability-based Maintenance, Electrical Power Distribution, Erratic Power Supply.

Introduction

Maintenance of electrical equipment is a guarantee for their improve life time, performance and sustainability. This is because maintenance is vital for continuous operation of such equipment as its attainment is a function of quality and quantity production using electrical energy. Maintenance can be defined as those activities and actions that directly retain the proper operation of an item or restore that operation when it is interrupted by failure or some other anomaly (Udo, 2020). Common maintenance approach involves: periodic maintenance, corrective maintenance, breakdown maintenance and preventive maintenance among others. There is yet another type more meticulous and sufficient than the aforementioned known as Reliability-based Maintenance. Reliability-Based Maintenance (RBM) is emerging from the realization that equipment failure probability is not linear. Reliability-based maintenance is an in-depth, highly involved process that seeks to analyze all the possible failure modes for each piece of equipment, and customize a maintenance strategy for each individual machine.

Electrical energy is required to power industrial processes and to produce goods, equipment and services in a vast majority of productive sectors, within an economy. Nwankwo and Njogo (2019) revealed that insufficient, unreliable and costly access to electricity has remained a binding constraint to businesses in Nigeria. According to Madu (2018) over the past two decades, the limited growth of Nigeria's electricity supply industry, combined with the high cost of diesel and petrol, has crippled the growth of the country's productive and commercial industries. Additionally, it stood as obstacle to the creation of jobs in the Nigeria's electricity supply industry, adding to the burden of unemployment in a large and rapidly growing population that suffer from uneasy and unstable access to electricity. Consequent upon the foregoing maintenance of electrical equipment derive its relevance and subsequently becomes imperative in production and services circles. Electrical power distribution systems are not an exception but need maintenance most.

Electrical power distribution is done by the Distribution Companies of Nigeria (DISCOs); it provides last mile services in the electricity supply value chain and ensures the connection between customers and the electricity grid. DISCOs are also responsible for transforming or stepping down electricity from the high voltage of 33 kV at the transmission level, to the lower voltage levels of 11kV and further 415V depending on the category of customer (Chinwuko et al, 2019). DISCOS are also responsible for the marketing and sale of electricity to customers amidst the drawback of the erratic nature of the power supply. There are 11 DISCOs in Nigeria, arising from the unbundling of the Power Holding Company of Nigeria (PHCN) (Chinwuko *et al.*, 2019). However, out of the 11 DISCOs in Nigeria, the emphasis of this study is on Abuja DISCO commonly called Abuja

Electricity Distribution Company (AEDC) whose areas of coverage includes Kogi State, Federal Capital Territory (FCT), Nassarawa and Niger States respectively.

The erratic nature of power supply to end users cripples their personal efforts as well as that of the industrial sector. This set back leads to economic difficulties and outright frustration (Aliyu, *et al.* 2019). Unreliable electricity supply to users also causes problems for industrial development and other facets that are run by electricity (Kaseke & Hosking, 2019). Nigeria's electricity supply industry operates far below expectation resulting in customers experiencing extreme load shedding and erratic electricity supply (AEDC, 2020). A sufficient reliability-based maintenance approach is needed this draw back.

Maintenance and Maintenance Strategies

Maintenance can be defined as those activities and actions that directly retain the proper operation of an item or restore that operation when it is interrupted by failure or some other anomaly (Udo, 2020). Maintenance is also defined as an activity to arrest, reduce or eliminate device deteriorations. The purpose of maintenance is to extend equipment lifetime, increase asset values (equipment conditions), and avoid costly consequences of failures (Bismark, 2020). Common maintenance approach involves: periodic maintenance, corrective maintenance, breakdown maintenance and preventive maintenance among others. Adoghe *et al*, (2019b) as well as Claudius (2020) in separate studies observed that electric power distribution companies have always employed breakdown maintenance approaches to keep their equipment in good working condition for as long as it is economic.

The maintenance problem in DISCOs is obvious in the common breakdown maintenance approach adopted by technical staff that always operates distribution equipment to failure before carrying out maintenance activity. The cost of maintaining system electric power distribution systems, especially through breakdown maintenance incurs huge expenditures on DISCOs. Claudius (2020) condemned the practice of waiting for equipment to fail before carrying maintenance as this interrupts planned distribution output and shortage in electricity supplied to consumers. It becomes necessary to adopt a more efficient maintenance approach such as Reliability-based Maintenance. The reliability of equipment is the probability that the equipment will continue to operate efficiently without sudden failure. Claudius (2020) stated that a proper maintenance should be done through designing and implementing Reliability-Based Maintenance (RBM) on electricity distribution system to reduce technical losses and enhance electricity supply to consumers.

Models to create connections between maintenance and the matching lifetime extension, asset condition, and reliability improvement are required in order to make sound decisions related to maintenance activities and also to enhance maintainability of equipment.

Maintainability is defined as the probability that a failed component or system will be restored or repaired to reach a specified condition, within a period of time when maintenance is performed in accordance with prescribed procedures (Bismark, 2020).

Common Maintenance Strategies: Outlined below are the more widely used maintenance strategies, as well as their pros and cons and situations when they are best applied. Typically we see plants employing either run-to-failure (only fix after a breakdown) or preventive maintenance (on a predetermined schedule) (Chinwuko *et al*, (2019). However, depending on the value of the asset or its criticality in the plant's operations, we may see this strategy escalated to predictive or even reliability-based maintenance.

Run-to-failure (breakdown maintenance): Run-to-failure maintenance is an acceptable strategy for equipment that is of minimal importance to operations (rarely used or duplicates the function of some other equipment) or has low cost. Take, for example, a N10, 000.00 belt feeder, whose lifetime value can be extended by 10% by servicing it every 3 months. How hard are you willing to work to save N 1000.00? For a non-critical piece of machinery, the answer should be "not hard." Equipment designated as run-to-failure are fixed in the event of a breakdown (by repair, restoration or parts replacement) until it is more feasible to simply order a replacement equipment.

Preventive (scheduled) maintenance (PM): This strategy is employed by most companies and almost all small to mid-sized companies make exclusive use of it. Preventive maintenance consists of assets being taken offline, inspected at periodic, predetermined intervals and repaired if necessary. Although it's a relatively easy strategy to set up and execute, it can prove quite costly in the long run as a majority of the time these inspections are a straightforward pass. It's recommended that serious attention is given to the efficiency of these schedules. Annual review of a schedule's effectiveness in raising overall equipment effectiveness by preventing breakdowns and see if the schedule can be lengthened or swapped out for predictive maintenance is ideal.

Predictive maintenance (PdM): PdM is a condition-based approach to asset management. Typically, monitoring equipment is linked to a CMMS and generates work orders based on some meter reading (PSI, vibration analysis, widgets/hour) gathered by the monitoring device. It may also be simpler than this, such as visual inspection by operators on the quality or speed at which the equipment is performing. Eg. A conveyor drops below 1000 widgets per hour, trigger an inspection work order. The advantage of predictive maintenance (over PM) is the potential for cost savings from reduced man-hours spent on maintenance, and more insight as to the performance and potential issues arising with the machine. ie: Vibration analysis + visual inspection gives more insight than visual inspection alone . Consequently, the insufficiency of the foregoing gave birth to Reliability-based Maintenance.

Reliability-based maintenance (RBM): Reliability-Based Maintenance (RBM) is another name for Reliability-Centered Maintenance (RCM). Emerging from the realization that equipment failure probability is not linear, reliability centered maintenance is an in-depth, highly involved process that seeks to analyze all the possible failure modes for each piece of equipment, and customize a maintenance strategy for each individual machine. The general consensus is that RBM is too sophisticated a technique to be of much practical use. RBM is therefore reserved for an elite class of organizations that have already mastered the basics of maintenance such as prevention maintenance, basic inspections and predictive maintenance.

Need for Reliability-Based Maintenance in Distribution Facilities

The function of the electrical power distribution system is to deliver energy to end users efficiently (Federal Republic of Nigeria FRN 2020). According to Luis, (2020). Ohanu, (2021) and Izuegbunam, *et al.*(2021). It is expected to supply basic national needs of residential, lighting, heating, refrigeration, air conditioning. The system should make critical supply of power to governmental, industrial, financial, commercial, medical and other communities (AEDC,2020). Nigeria with a population of about 200million and depended on 3,500Mega Watts (MW) of electricity generated is infinitesimal, thus; aggravating the expectancy of Nigerians' electricity utilization to the tune of 6,000MW (Flyn, and Bartosz, 2019).

It is sad to note that despite gross short fall in electricity distributed,40 percent of it is lost before utilization. Over the past five years, evidence from literature has revealed that only 60 percent of the electrical power distributed reach the end users or customers because of poor maintenance practices adopted in the distribution system equipment (Claudius, 2020). This situation gives birth to power problems. Adoghe, et al (2019a), as well as Claudius (2020) observed that electrical power distribution companies have always employed breakdown maintenance approaches to keep their equipment in working condition for as long as it deceptively appears economical. Power system problems could also arise through any number of situations, such as, heavy start-up loads, faulty distribution components, and even typical background electrical noise (Seymour, 2021). Recent global blackouts indicated that the root cause of almost all of major power system disturbance is voltage collapse rather than the frequency conditions (Duru-Oguzie, 2020).

Aliyu, *et al.* (2019) further asserted that the erratic nature of power supply cripples the industrial sector, which leads to economic difficulties. Lack of reliable electricity also causes problems for industrial development and other facets that are run by electricity (Kaseke & Hosking, 2019). Nigeria's electricity supply industry operates far below expectation resulting in customers experiencing extreme load shedding and erratic electricity supply (AEDC, 2020). To meet these challenges, a robust reliability-based maintenance approach is required.

Concept of Reliability-Based Maintenance

The RBM was developed over a period of thirty years, but was first defined in 1978 by Stan Nowlan & Howard Heap in a report titled Reliability-based Maintenance commissioned by the U.S. Department of Defense (Adoghe, et al, 2019a). The reliability of equipment is the probability that the equipment will continue to operate efficiently without sudden failure. Reliability-Based Maintenance (RBM) is another name for Reliability-Centered Maintenance (RCM). Reliability

Based Maintenance (RBM) is a very powerful methodology which, when properly applied, can drive significant improvements in equipment reliability and plant performance while, at the same time, making sure that the money being spent on Predictive and Preventive maintenance programs is optimized. In its simplest definition, RBM is an analytical process made possible through standardized maintenance and reporting, and it is used to continuously advance the maintenance strategy.

Emerging from the realization that equipment failure probability is not linear, reliability centered maintenance is an in-depth, highly involved process that seeks to analyze all the possible failure modes for each piece of equipment, and customize a maintenance strategy for each individual machine. RBM is the process of determining the most effective maintenance approach that is more cost-effective without any environmental consequences. RBM is a sophisticated system that is reserved for an elite class of organizations that have already mastered the basics of maintenance such as prevention maintenance, basic inspections and predictive maintenance (Valakevicius, *et al* (2020). The goal of reliability-based sintered maintenance is to create such a maintenance strategy, so that the overall operating costs are minimized while preserving required rates of reliability, safety and environment-friendly attitude in the equipment to be operated.

According to Valakevicius *et al* (2020), RBM should meet four basic principles to be considered a genuine application of reliability-based maintenance:

i. The analysis is scoped and structured to preserve system function.

ii. The analysis identifies how functions are defeated (failure modes).

iii. The analysis addresses failure modes by importance.

iv. For important failure modes, the analysis defines applicable maintenance task candidates and selects the most effective one.

According to Valakevicius *et al* (2020) RBM is a structured process which sequentially asks the following seven questions about the asset or system under review:

i. Functions - what are the functions and associated performance standards of the asset in its present operating context?

ii. Functional Failures - in what ways does it fail to fulfill its functions?

iii. Failure Modes - what causes each functional failure?

iv. Failure Effects - what happens when each failure occurs?

v. Failure Consequences - in what way does each failure matter?

vi. Proactive Tasks - what can be done to predict or prevent each failure?

vii. Default Actions - what should be done if a suitable proactive task cannot be found?

Each of these questions is discussed briefly below:

Functions and Performance Standards: A key concept of RBM is the understanding that the primary purpose of a preventive maintenance program is to ensure that equipment continues to do what the business requires it to do, in its present operating context. Therefore, the first step is to ensure that we fully understand what it is that we need the equipment to do (its functions), and the level of performance that is required if the business is to meet its objectives.

The functions of equipment consists of Primary Functions (normally associated with the reasons that the equipment was acquired in the first place), and Secondary Functions (additional requirements, often to do with Safety, Efficiency etc.). For many equipment items, there can be several (potentially as much as 20 or 30 in some cases) functions. For each of these functions, we must, where possible, quantify the level of performance required. For example, it would not be sufficient to state that the Primary Function of a pump is to pump a liquid from A to B, we would also need to specify the flow rate required, if production output targets were to be met. As a result, if done properly, answering this first question alone can take between 25% and 35% of the total time required for an entire RBM analysis.

Functional Failures: Functional Failures (or Failed States) simply define, for each function, the states under which the equipment does not fulfill its functions. For each function, there is a need to consider both complete failure (for example where the equipment fails to operate at all), and partial failures (where the equipment operates, but does not operate at a level sufficient to meet the performance standard associated with that Function.

Failure Modes: Once each Functional Failure has been identified, the next step in the RCM process is to identify all the events which are reasonably likely to cause each failed state. These events are known as Failure Modes. "Reasonably likely" Failure Modes include those which have occurred on the same or similar equipment operating in the same context, failures which are currently being prevented by existing maintenance regimes, and failures which have not happened yet but which are considered to be real possibilities in the context in question. The list should include failures caused by human errors (on the part of operators and maintainers) and design flaws so that all reasonably likely causes of equipment failure can be identified and dealt with appropriately. It is also important to identify the cause of each failure in enough detail to ensure that time and efforts are not wasted trying to treat symptoms instead of causes. On the other hand, it is equally important to ensure that time is not wasted on the analysis itself by going into too much detail.

Failure Effects: The fourth step in the RCM process entails listing Failure Effects, which describe what, happens when each failure mode occurs. These descriptions should include all the information needed to support the evaluation of the consequences of the failure (in the next step in the process), such as;

i. What evidence (if any) that the failure has occurred.

ii. In what ways (if any) it poses a threat to safety or the environment. In what ways (if any) it affects production or operations.

iii. What physical damage (if any) is caused by the failure?

iv. What must be done to repair the failure?

Identifying the relevant Failure Modes and Failure Effects is also a comparatively lengthy activity – typically requiring around 30-35% of the time required for the entire RBM analysis.

Failure Consequences: Another key concept underpinning RBM is that the primary objective of a Preventive Maintenance program is not necessarily to avoid or minimize failures themselves, but to avoid or minimize the consequences of those failures. There is little point in spending a lot of time and money preventing failures that have little or no consequences associated with them. On the other hand, if a failure has serious consequences, we may be able to justify going to great lengths to avoid those consequences. In this way, the RBM process focuses attention on the maintenance activities which have most effect on the performance of the organization, and diverts energy away from those which have little or no effect.

The fifth step in the RBM process classifies the consequences associated with each failure mode as belonging to one of the following four groups:

i. **Hidden failure consequences:** Hidden failures have no direct impact, but they expose the organization to multiple failures with serious, often catastrophic, consequences. (Most of these failures are associated with protective devices which are not fail-safe.).

ii. **Safety and environmental consequences:** A failure has safety consequences if it could hurt or kill someone. It has environmental consequences if it could lead to a breach of any corporate, regional, national or international environmental standard.

iii. **Operational consequences:** A failure has operational consequences if it affects production (output, product quality, customer service or operating costs in addition to the direct cost of repair).

iv. **Non-operational consequences:** Evident failures which fall into this category affect neither safety nor production, so they involve only the direct cost of repair.

The consequence evaluation process also shifts emphasis away from the idea that all failures are bad and must be prevented. In so doing, it focuses attention on the maintenance activities which have most effect on the performance of the organization, and diverts energy away from those which have little or no effect.

Proactive Tasks: In RBM, failure management techniques are divided into two categories:

i. **Proactive Tasks:** these are tasks undertaken before a failure occurs, in order to prevent the item from getting into a failed state. They embrace what is traditionally known as 'predictive' and 'preventive' maintenance, although we will see later that RBM uses the terms Scheduled Restoration, Scheduled Discard, and Condition-based Maintenance.

ii. **Default Actions:** these deal with the failed state, and are chosen when it is not possible to identify an effective proactive task. Default actions include failure-finding, redesign and run-to-failure.

Many people still believe that the best way to improve equipment reliability is to do some kind of proactive maintenance on a routine basis. Conventional wisdom suggested that this should consist of overhauls or component replacements at fixed intervals.

Default Actions: RCM recognizes three major categories of default actions, as follows:

i. Failure-Finding: Failure-finding tasks entail checking hidden functions periodically to determine whether they have failed (whereas condition-based tasks entail checking if something is failing).

ii. Redesign: redesign entails making any one-off change to the built-in capability of a system. This includes modifications to the hardware and also covers once-off changes to procedures.

iii. No Scheduled Maintenance: as the name implies, this default entails making no effort to anticipate or prevent failure modes to which it is applied, and so those failures are simply allowed to occur and then repaired. This default is also called run-to-failure.

Advantages of Reliability-based Maintenance.

Reliability-based Maintenance of equipment in any facility has some concomitant advantages over other maintenance approaches, consequently, implementing the Reliability-based Maintenance method results in:

1 Rapid drop in maintenance cost

2 Optimized maintenance staff tasks

3 Very high return on investment (ROI) and implementation

4 Drop in down time due to optimal maintenance tasks

5 Better control on asset management and lifetime expectancy

Conclution

Many challenges still abound when maintenance is not sufficient in the attempt to ensure proper operation of equipment in any facility. It therefore becomes necessary to decide on the maintenance approach that can pull numerous advantages. Of the maintenance approaches listed and discussed, Reliability-based Maintenance was found to be more remediable and preventive.

It has the accompanying advantages of: drop in maintenance cost; optimized staff tasks; very high return on investment (ROI) and implementation; drop in down time due to optimal maintenance tasks and finaly, better control on asset management and lifetime expectancy. The foregoing credits place RBM in contradistinction with other maintenance approaches and therefore makes it to be rightly considered as a Panacea to erratic power supply which is highly or majorly a result of insufficient maintenance of power equipment.

Recommendations.

Based on the content of the paper, the following recommendations were made:

1 The strategic management of Abuja Electricity Distribution Company should as a matter of urgency embrace and direct technical staff supervisors to adopt the tenets of reliability-based maintenance as the most efficient maintenance practice.

2 Management of Abuja Electricity Distribution Company should organize capacity building for technical staff supervisors on the effective and efficient implementation of the reliability-based maintenance approach.

3 Management of Abuja Electricity Distribution Company should organize public Workshops, Seminars, Conferences and Symposia for the electricity power stakeholders to acquaint them with the reliability-based maintenance approach so that they can take advantage of it at their different work places.

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