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OPTIMIZING PLANT'S MAINTENANCE COST USING STRATEGIC SWITCHING APPROACH

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Abstract Inadequate supply of public electricity in Nigeria has affected the productivity of many manufacturing industries. Electric generating plant is being used as a standby supplement to public electricity at outage hours. The high cost of running and maintenance of this generating plant has adversely affected the sustainability of the industry. A maintenance strategic switching approach was developed to minimize the cost of running the electric generating plant in the industries. Maintenance strategic switching and cost control parameters are preventive, repair/corrective and replacement. The maintenance cycle for each of the components served as tool for the determination of cumulative sum of maintenance cost from which the minimum cost schedule was selected. Data collected on power machinery from a water generating company was used to test the model. The least probability of failure (non-progressive deterioration) for components was recommended for adoption. There was a significant saving in maintenance cost of components under the non-progressive deterioration. In the 750 schedule, while the cost of maintenance with progressive deterioration was N149, 677, that of non-progressive, least failure probability was N75, 960.35 with savings of 49.25% over the former. Therefore, most economic schedule was 750 cycles. This scheme predicted for the organization the optimal maintenance strategy to utilize.

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1. INTRODUCTION

Inadequate supply of public electricity in Nigeria has affected the productivity of many manufacturing industries. Electric generating plant is being used as a standby supplement to public electricity at outage hours. The high cost of running and maintenance of this generating plant has adversely affected the sustainability of the industry. A maintenance strategic switching approach was developed to minimize the cost of running the electric generating plant in the industries. Maintenance strategic switching and cost control parameters are preventive, repair/corrective and replacement. The maintenance cycle for each of the components served as tool for the determination of cumulative sum of maintenance cost from which the minimum cost schedule was selected. Data collected on power machinery from a water generating company was used to test the model. This scheme predicted for the organization the optimal maintenance strategy to utilize. A sequence of maintenance policies that was found to give minimum cost were presented for the organization.

One of the greatest challenges that affect a greater percentage of manufacturing industries all over the world, especially in Nigeria, today is on the issue of adequate, timely and effective maintenance (Eti and Emovon, 2005). The resultant effects of the aforementioned are uneconomic management of the production industry (Grant and Eugene, 1989). The value of the machine's output is independent of age, but the natural probability of machine failure increases with age (Ashayeri et al., 1996). Preventive maintenance can be applied to reduce the probability of machine failure (Okah-Avae, 1996). The challenge is to select an optimal preventive maintenance policy / model for the period of ownership (Preinreich, 1990). One of the major factors of production is the machinery (Okah-Avae, 1996). The condition or state of machines used for production goes a long way to determining whether there would be increase in profit, loss of man-hours and even downsizing of the total workforce. Failure rates, maintenance types and technological advancement played a prominent role in determining the status of the production industry (Okoli and Akhighemidu, 2003). This challenge calls for a continuous non-increasing maintenance expenditure (Pradhan and Bhol, 2006). The necessary condition for machine age at sale is critical in the determination of optimal economic utility of machinery (Gertsbakh, 1977). It is therefore important to develop a good maintenance scheme for the production machinery (Shepard, 2001). It can be seen that electric generating plants constituted the highest percentage of failures in production machinery in the industry (Eti and Emovon, 2005; Wheelwright, 2008). For this reason, economic maintenance of the generating plant needs to be critically looked into.

Most production industries all over the globe today are struggling to stay afloat in achieving productivity Austin and Burns, 1985). Amidst the challenges of machine failures during production which usually affect the profitability was increased total annual overhead cost incurred in operations (Martand, 2007). The durability of machinery in a production industry is an ultimate goal for economic consideration in every aspect of production (Harvey, 1989). This study seeks to develop a strategy that will provide maximum economic maintenance of electric generating plant in a selected production industry. This approach can then be used for any other selected industry taken into consideration the major parameters that constituted economic maintenance for that industry. The strategy provided will also enhance system economy in term of manufacturing outputs. Increased annual profits would give room for employment of skilled and the unskilled categories of labor into the company (Levin et. al., 1989). The aim of this study is to develop a strategy for optimizing maintenance of an electric generating plant in a production industry using strategic switching approach. A mathematical model was developed to optimize the process. The model was applied to a water Corporation in Nigeria. The research provides an optimal strategy for economic maintenance of electric-power generating plant in Water Corporation in Nigeria.

1.1. General Review of Maintenance Concept

Effective utilization of electric generating plant used as an alternative power source for production has a significant positive effect in the successful running of manufacturing industry, most especially in the power challenging sectors of Nigerian manufacturing industries. Machineries are the basic tools required by producers to generate outputs (Hans, 1999). There are five types of equipment / machinery: production machinery; auxiliary machinery; materials handling equipment; transportation equipment; and office equipment (Corder, 1976).

Production machinery: this refers to all the components in a machine or equipment required for active production process. Examples of production machinery in Water Corporation are high-lift pumps, low-lift pumps, generating sets (Aderoba et. al., 2003). Auxiliary machinery: this is the category of machines which does not play a primary role in the production process in the industry. This type of machines includes the blower, backwashing fans, fuel tank etc. (Aderoba et-al, 2003). Materials handling equipment: these are the machines responsible for the ease of conveying materials or products from one location in the factory to another without much human effort. These include; forklift, small cranes, overhead cranes and trolleys (Eti and Emovon, 2005). Transportation equipment: these are machines required for the conveyance of goods and services from one point to another for the benefit of the industry. Examples are pick up vans and tankers, (Aderoba et. al., 2003). Office equipment: these are the accessories required in the office for the comfort and ease of working condition for staff and operators of equipment in the industry. These include; furniture of all types- chairs, tables, air-conditioners, file rack etc. (Dunlop, 1990). Among the aforementioned categories of machinery, production machinery was considered. Under this production machinery, electric generating plant and its mechanical components was selected for this study.

According to Ashayeri et-al, (1996), the optimal policy for running a manufacturing industry required non-increasing rate of maintenance expenditure. The machine age at sale is critical in the determination of optimal efficiency and durability of the machine. There must be explicit distinction between machine's natural failure rate and the actual failure rate to warrant preventive maintenance policy (Tiwari & Seppala, 2009). Replacement of assets is one of the most important and frequently made decisions in maintenance system. The net present value decision model described discounted maintenance cost as difference between cash flows and terminal (salvage) values of the replace and do-not-replace alternatives (Ballal & Lewis, 2009).

A huge drop in annual machinery maintenance costs with reduced failure rate can be achieved year after year if a good maintenance practice is in place. The cost of maintenance is measured with failure rate of the machine on a yearly basis (Grant and Eugene, 1989; Ashayeri et al., 1996). Precision maintenance ensures production at less operational cost (Wheelwright, 2008). This is because it improves the reliability of the machinery (Martand, 2007). In preventive maintenance, equipment is maintained before the occurrence of break-down (Basu, 1989). Recent studies have shown that preventive maintenance is effective in preventing age related failures of the equipment (Basu, 1989). For random failure patterns which amount to 80% of the failure patterns, condition monitoring proves to be effective (Denbow, 2009). In corrective maintenance, equipment is maintained after breakdown (Lawal, 2000). This maintenance is often most expensive because worn equipment can damage other parts and causes multiple damage (Lawal, 2000). Corrective maintenance is carried out on all items where the consequences of failure or wearing-out are not significant, and the cost of this maintenance is not greater than preventive maintenance (Hans, 1999; Denkena, et. al., 2009). Proper management of the aforementioned maintenance strategies will enhance economic maintenance of the equipment in the production industry, especially in Water Corporation. However, if maintenance system is not managed strictly, major damages may occur and the cumulative cost of corrective maintenance may be exorbitant. This is the negative trend of maintenance in most of the industries today.

Electric power is the major factor for consideration in setting up any production outfit or industry anywhere in the world. This required adequate planning for power resources in order to avoid disruptions due to power outages along production or manufacturing lines in the industry. Hence, the need for a strategy of optimizing maintenance of the electric generating plant in the Water Corporation. Most industries today are grossly affected by inadequate and ineffective maintenance challenges. Maintenance approach by most production industries today cannot cater for the new trends in the maintenance of components of the electric generating plant. The approach of industries to maintenance of this nature is based on conventional progressive deterioration. This paper has provided an alternative approach by considering the non-progressive deterioration. The rest of paper is presented this: methods of approach are detailed in Section 2; results and discussion are in Section 3; Section 4 concludes the study; and acknowledgements are presented in Section 5.

2. METHODOLOGY

2.1. Modelling Conditions

Modeling conditions involved in this study is based on maintenance strategies namely; preventive/routine, repair/displacement, and replacement:

Preventive / routine maintenance: this is a form of maintenance that is carried out to enable the elongation of the lifespan of any of the machine components. It can be carried out by following the stipulated period/cycle by the manufacturers, in hours, weeks or on a monthly basis, depending on the service requirement of the machine (Li and Nilkitsaranont, 2009).

Replacement: this is the form of corrective maintenance that is done by making necessary changes to affected machine parts to restored efficient functionality of the machine (Lawal, 2000).

Displacement/repair: this is the maintenance that is carried out when a particular technological advancement or innovation performs better that the component used initially or by reason of high output demand. The equipment can be upgraded through repairing/displacement of some of the components (Denkena et al, 2009). Components can undergo progressive and non-progressive deterioration (Preinreich, 1990; Corder, 1976). Presented in Fig. 1 is the proposed maintenance strategic switching approach showing the relationships among the considered parameters, namely: failure pattern of components of the plant; maintenance groupings (preventive, replacement, and repair) of components; progressive and non-progressive policies; and strategic switching to minimize cumulative maintenance cost of plant.

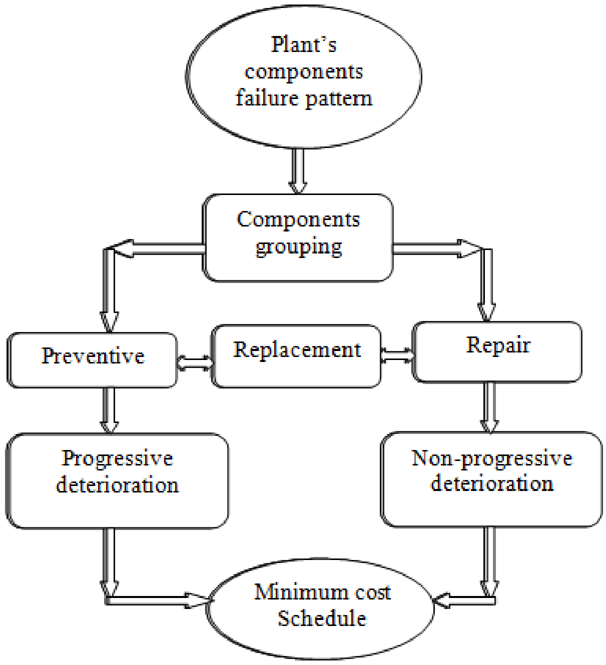

Fig. 1 Hierarchical Strategic Switching of Maintenance Parameters

2.2. Model Development

In developing the model, the parameters considered include the Reliability of the machines, $R(t)$, the Probability of failure of the machines, $P(t)$ (Taha, 2008). The maintenance cycle for preventive maintenance is, t_p, the maintenance cycle for repair maintenance is, t_r, and the maintenance cycle for replacement maintenance, t_c, were put into consideration. The economic preventive maintenance rate is given as, $\lambda_p^i t$, while that for economic repair maintenance is given as $\lambda_r^i t$, and economic replacement maintenance is $\lambda_c^i t$. Where, $\lambda_p^i t$ is the failure rate for preventive maintenance, $\lambda_r^i t$ is the failure rate for repair maintenance, $\lambda_c^i t$ is the failure rate for replacement maintenance, then reliability based on negative exponential distribution of equipment /component i in plant j is respectively expressed as:

$$R(t)_p^i = e^{-\lambda_p^i t} \qquad \text{for } t \le t_p \tag{1}$$

$$R(t)^i_r = e^{-\lambda^i_r t} \qquad \text{for } t_p \le t_r \tag{2}$$

$$R(t)^i_c = e^{-\lambda^i_c t} \qquad \text{for } t_r < t \le t_c \tag{3}$$

The corresponding probabilities of component failures for preventive, repair and replacement are respectively given as:

$$P(t)^i_p = 1 - R(t)^i_p \tag{4}$$

$$P(t)^i_r = 1 - R(t)^i_r$$

(5)

$$P(t)^i_c = 1 - R(t)^i_c \tag{6}$$

where, the preventive cost per cycle for component, $i = C^i_p$, repair cost per cycle for component, $i =$ C^i_r and replacement cost per cycle for component, $i = C^i_c$,

In the formulation of the model for the optimal maintenance of electric generating plant, the conventional progressive deterioration approach was applied. Progressive deterio-ration refers to the maintenance strategy where the components of the plant are allowed to keep on working without replacing the component until they get damaged. This type of maintenance planning is prevalent in many developing countries. The cost of maintenance based on progressive deterioration of the component, *i* is respectively modeled as,

$$C^i_p m = C^i_p P(t)^i_p \tag{7}$$

$$C^i_r m = C^i_r P(t)^i_r \tag{8}$$

$$C^i_c m = C^i_c P(t)^i_c \tag{9}$$

Where, $C^i_p m =$ total cost of components for preventive maintenance; $C^i_r m =$ total cost of components for repair maintenance; and $C^i_c m =$ total cost of components for replacement maintenance

The outcomes of equations (4), (5), (6), (7), (8) and (9) were used to estimate total maintenance cost for the components (i, … , k) in the plant j based on maintenance cycle expressed as equation (10).

$$C^i_j = \sum_{i=1}^{k} C^i_p P(t)^i_p + \sum_{i=1}^{k} C^i_r P(t)^i_r + \sum_{i=1}^{k} C^i_c P(t)^i_c \tag{10}$$

and this is equivalent to,

$$C^i_m = \sum_{i=1}^{k} C^i_{pm} + \sum_{i=1}^{k} C^i_{rm} + \sum_{i=1}^{k} C^i_{cm} \tag{11a}$$

The optimal cost of maintenance is the minimum cost, C_m^{i*}

That is, $$\min C_m^i = C_m^{i*} \qquad (11b)$$

A new concept known as non-progressive deterioration was developed and integrated into the model. Non-progressive deterioration of the components explains the situation where the machine's components are replaced or restored before the actual failure of the plant. It was assumed that the replacement of the failed component has restored the plant to a new status. If the components are restored to as new ones by maintenance actions that is; non-progressive deterioration, then the maintenance cost for the three scenarios are respectively,

$$C_p^i m = t / t_p C_p^i P(t)_p^i \qquad (12)$$

$$C_r^i m = t / t_r C_r^i P(t)_r^i \qquad (13)$$

$$C_c^i m = t / t_c C_c^i P(t)_c^i \qquad (14)$$

Where, t is the maintenance cycle time, t_p is the maintenance cycle for preventive maintenance, t_c is the maintenance cycle for replacement maintenance, and t_r is the maintenance cycle for repair maintenance.

Similarly, as formulated in progressive deterioration, the total cumulative cost for non-progressive deterioration maintenance system is then given as

$$C_m^i = \sum_{i=1}^{k} t / t_p C_{pm}^i + \sum_{i=1}^{k} t / t_r C_{rm}^i + \sum_{i=1}^{k} t / t_c C_{cm}^i \qquad (15)$$

The optimal cost is the minimum cost of maintenance, C_m^{i**}

That is, $$\min C_m^i = C_m^{i**}$$

In the three scenarios, the replacement time of the machine/component happens at maintenance cycle time, t when the cumulative cost of maintenance C_m^i is greater than initial cost of components, C_i.

For a single component;

$$C_m^i = C_{pm}^i + C_{rm}^i + C_{cm}^i \qquad (16)$$

If $C_m^{i*}, C_m^{i**} > C_i$ then replace the component and if otherwise the components should not be replaced, instead, other types of maintenance policies may be considered.

2.3. Model Application to a Water Corporation's Generating Plant

This is an establishment vested with the responsibilities of producing on a constant basis, highly hygienic potable water to the entire population of a city in Nigeria. The entire city has a well structured pipeline network for the effective distribution of water to towns and villages. Due to the epileptic nature of public electric power supply to energize the pumps, all the water schemes, booster stations and head-works are powered by the aid of heavy duty generating sets. This varies from 50KVA to the maximum of 2.2MVA (i.e. 2200KVA). There were over seventy (70) of such heavy duty generators in the city. Data on generating plant components (alternator, fuel pump, oil filter, fuel filter, lubricant, fan belts, bearings lubrication, valve springs, air cleaner element, injectors, overhauling, etc) and their maintenance schedules (preventive, repair and replacement) were collected. These data were analyzed as shown in Table 1. Table 1 is the summary of the sampled components of the electric power generating plant that was considered for the study. The components were grouped into the maintenance schedules of preventive, repair and replacement based on their respective maintenance cycles as stipulated by the manufacturer. The maintenance parts ranging from the oil filter, fuel filter, lubricant for the servicing of the generator, alternator belt drive, radiator (flushing), fan belts, bearing lubrication, valve springs, injector tubes, air cleaning element, fuel pump injectors and overhauling are constituents of maintenance materials that required replacement, routine checks, or displacement as the case may be. These spare- parts were re-grouped according to the standardized time/schedule of maintenance as specified by the manufacturer.

Preventive maintenance, for example, the stipulated change/check period was 250 hours for the oil filter, fuel filter, lubricating, radiator flushing and fuel pump injector. The items for repair were fuel pump injectors and overhauling at 1000 and 20,000 hours, respectively. At this time/schedule, the user was required to carry out necessary maintenance as stipulated. The schedules for replacements were also indicated against their materials. For the basis of this study, the cost of maintenance of each of the components of the plant was considered in evaluating the financial or economic implication of the respective maintenance strategy. The respective schedules of maintenance were presented in the table with the costs in Naira (Naira, N, is the symbol for Nigeria currency, N250 is equivalent to 1USD approx.). The schedules were re-grouped into respective maintenance policies (preventive, repair and replacement), which served as input into the model.

Table 1 Maintenance Schedule for 350KVA Perkin Generator

S/N	Materials/parts	Preventive (hrs)	Repair (hrs)	Replacement (hrs)	Cost(N)
1.	Oil Filter	250	-	-	
2.	Fuel Filter	250	-	-	26,000

3.	Lubricant	250	-	-	
4.	Alternator Belt Drive	-	-	250	29,000
5.	Radiator (Flushing)	250	-	-	5,000
6.	Fan Belts	-	-	250	3,000
7.	Bearings Lubrication	42	-	250	21,800
8.	Value Springs	-	-	250	15,500
9.	Injector Tubes	250	-	250	21,250
10.	Air Cleaner Element	168	-	2,500	21,000
11.	Value Seat Inserts	-	-	250	10,000
12.	Fuel Pump Injectors	-	1,000	-	16,500
13.	Overhauling	-	20,000	20,000	400,000

In Table 2, the detailed schedule maintenance chart for the preventive aspect of the study is shown. The table is divided into fourteen (14) time/schedule intervals. For example, radiator flushing was to be carried out at every 250 hours. Then the next schedule was 500 hours. All components covered under preventive maintenance were scheduled into the 250 hours intervals [items (i), (ii) and (v)], 42 hours interval and 168 hours as indicated on the manual. The duration of replacement of maintenance materials was mainly dependent on the reliability or failure rate of the plant components. This explains why changes in intervals for some materials were 42 hours, 250 hours, 1000 hours and 2000 hours depending on the type of maintenance material with respect to its lifespan (Table 2).

Table 2 Time Schedule for Preventive Maintenance

Material/ cycle	**Servicing, oil filter, fuel filter, lubricant (i) (hrs)**	**Radiator flushing (ii) (hrs)**	**Bearing lubrication (iii) (hrs)**	**Air cleaner element (iv) (hrs)**	**Injector tubes (v) (hrs)**
1	250	250	42	168	250
2	500	500	84	336	500
3	750	750	126	504	750
4	1000	1000	168	672	1000
5	1250	1250	210	840	1250
6	1500	1500	252	1008	1500
7	1750	1750	294	1176	1750
8	2000	2000	336	1344	2000
9	2250	2250	378	1512	2250
10	2500	2500	420	1680	2500
11	2750	2750	462	1848	2750
12	3000	3000	504	2016	3000
13	3250	3250	546	2184	3250
14	3500	3500	588	2352	3500

Table 3 is the time schedule interval for replacement maintenance for the plant. The overhauling was to be carried out after every 20,000 hours. The injector pump tubes required check and replacement after every 2500 hours. Other items under replacement maintenance were alternator's belt drive, fan belts, bearing lubrication, valve springs, air cleaner element and fuel pump. Materials for maintenance under replacement were assumed to be completely replaced with new ones. Given in Table 4 are the schedule intervals for repair maintenance for the plant. The materials covered here are mainly fuel pump injector and the overhauling. The fuel pump injector was done at every 1000 hours while the overhauling at every 20,000 hours. It took a longer period for these materials to get worn-out.

Table 3 Time Schedule for Replacement

Spare parts/ cycle	Alternator belt drive (hrs)	Fan belt (hrs)	Bearing (hrs)	Valve springs (hrs)	Injector tubes (hrs)	Air cleaner element (hrs)	Fuel pump (hrs)	Overhauling (hrs)
1	250	250	250	250	2500	2500	2000	20000
2	500	500	500	500	5000	5000	4000	40000
3	750	750	750	750	7500	7500	6000	60000
4	1000	1000	1000	1000	10000	10000	8000	80000
5	1250	1250	1250	1250				
6	1500	1500	1500	1500				
7	1750	1750	1750	1750				
8	2000	2000	2000	2000				
9	2250	2250	2250	2250				
10	2500	2500	2500	2500				
11	2750	2750	2750	2750				
12	3000	3000	3000	3000				
13	3250	3250	3250	3250				
14	3500	3500	3500	3500				

Table 4 Time Schedule for Repair

Parts	Time/(hrs)	(hrs)	(hrs)	(hrs)
Fuel Pump Injector	1000	2000	3000	4000
Overhauling	20,000	40,000	60,000	80,000

Time intervals of failures for these components were arranged based on their failure tendency (probability of failure) which can be either long-termed or short. For example, overhauling is long-termed. The parts affected here include pistons, rings, sleeves, and connecting rods, whose wear frequency is very low. Fuel filters and oil filter elements have very short useful lifespan because of the short-termed collapsible nature of the internal structure of the elements.

3. RESULTS AND DISCUSSION

The results obtained after testing the model are highlighted in this section. The resulting probabilities of failure obtained from the case study are as presented in Tables 5- 14.

3.1. Reliability of the Plant under Preventive Policy

Reliability for preventive maintenance at 750 hrs schedule is shown in Table 5a. The least reliable policy was obtained at 84 hour-cycle while the most reliable one was at 500 hour-cycle. Under the 1500 schedule, the least reliable component was obtained at 42 hour maintenance cycle while the most reliable was at 500 hour cycle. These were also replicated in schedules 2250 and 3000, respectively.

Table 5a Reliability $R(t_p)$ of the Plant under Preventive Policy

$R(t_p)$/ Actual mtce Time (hrs)	750 (hrs)	1500 (hrs)	2250 (hrs)	3000 (hrs)
42	1.769×10^{-8}	3.13×10^{-16}	5.54×10^{-24}	9.8×10^{-32}
84	0.0001	3.33×10^{-4}	2.35×10^{-12}	3.13×10^{-6}
250	0.0498	0.0025	0.00012	6.14×10^{-6}
336	0.1069	0.0114	1.22×10^{-3}	1.31×10^{-4}
500	0.2231	0.0498	0.111	2.48×10^{-3}

Table 5b Probability of failure $P(t_p)$ under preventive maintenance policy

$P(t_p)$ / Actual mtce Time (hrs)	750 (hrs)	1500 (hrs)	2250 (hrs)	3000 (hrs)
42	1.0000	1.0000	1.0000	1.0000
84	0.9999	1.0000	1.0000	0.9999
250	0.9502	0.9975	0.9999	0.9999
336	0.8930	0.8860	0.9978	0.9998
500	0.7769	0.9502	0.8890	0.9975

In Table 5b, the preventive maintenance policy for probability of failure, under the 750 schedule was presented. The least probability of failure occurs at the 500 maintenance cycle while the highest probability of failure occurs at the 42 hour maintenance cycle. Under the 1500 schedule, the least probability of failure occurs at the 336 hour- cycle, while the highest probability for this schedule occured at 42 and 84 maintenance cycles, respectively. This is also replicated in the 2250 and 3000 schedules. It could be noted here that the tendency of failure of the machine component occurs at the least maintenance cycle. It is therefore safer to replace the components before the end of this cycle to prevent premature failure of the component. There is need to pay particular attention to this maintenance schedule to avoid any unnecessary breakdown.

3.2. Reliability of the Plant under Replacement Policy

In the reliability Table 6a for replacement, in each of the schedules from 750 hour to 3000 hour, the reliabilities increases down the schedules. This indicates that the 20,000 maintenance cycle was the most reliable component under replacement maintenance. It is therefore cost effective to effect replacement at the higher hour cycle.

Table 6a Reliability $R(t_r)$ of components for Replacement Maintenance Policy

$R(t_r)$/ Actual mtce Time (hrs)	**750 (hrs)**	**1500 (hrs)**	**2250 (hrs)**	**3000 (hrs)**
250	0.0498	0.0025	0.0001	6.14×10^{-6}
500	0.2231	0.0498	0.0111	0.0025
750	0.3679	0.1423	0.0537	0.0185
1000	0.4724	0.2231	0.1054	0.0498
2500	0.7408	0.5488	0.4066	0.3012
20,000	0.9632	0.9277	0.8936	0.8607

In Table 6b, the probability of failure for replacement decreases down the table from the 750 schedule to the 3000 schedule. This meant that the highest probability of failure for replacement occurred at the lower maintenance cycle of 250, 500, 750 etc. The plant's components under the replacement maintenance were most reliable at the highest maintenance cycle than at the lower cycles. Maintenance should promptly be carried out at the time of attaining lower maintenance cycles. This will ensure that failure does not occur to disrupt production activities.

Table 6b Probability of Failure of components for Replacement Policy

Prob. of failure at Scheduled mtce cycle $P(t_r)$/ Actual mtce Time (hrs)	**750 (hrs)**	**1500 (hrs)**	**2250 (hrs)**	**3000 (hrs)**
250	0.9502	0.9975	0.9999	0.9999
500	0.7769	0.9502	0.9889	0.9975
750	0.6321	0.8577	0.9463	0.9815
1000	0.5276	0.4512	0.8946	0.9502
2500	0.2592	0.4512	0.5934	0.6988
20,000	0.0368	0.0723	0.1064	0.1392

3.3. Reliability of the Plant under Repair Policy

In Table 7a, it was observed that the reliability of the plant components increases from top to the bottom of each of the schedules from the 1000-20000 hrs. It was advisable to carry out maintenance at the period allotted to it. Failure to carry out such maintenance will allow the component to fail pre-maturely, and may adversely affect other components and thereby increase maintenance cost. This model made the provision that there was no need of waiting until the component got damaged before repair was done. This can be done by making the replacement before failure occurs (Table 7b).

Table 7a Reliability of components for Repair Maintenance Policy

Reliability at Scheduled mtce cycle $R(t_c)$/Actual mtce Time (hrs)	750 (hrs)	1500 (hrs)	2250 (hrs)	3000 (hrs)
1000	0.4724	0.2231	0.1054	0.0498
2000	0.6873	0.4724	0.3247	0.2231
3000	0.7788	0.6096	0.4759	0.3716
4000	0.8290	0.6873	0.5698	0.4723
20,000	0.9632	0.9277	0.8936	0.8607

Table 7b Probability of Failure of components for Repair Maintenance Policy

Prob. of failure at Scheduled mtce cycle $P(t_c)$/ Actual mtce Time (hrs)	750 (hrs)	1500 (hrs)	2250 (hrs)	3000 (hrs)
1000	0.5276	0.7769	0.8946	0.9502
2000	0.3127	0.5276	0.6753	0.7769
3000	0.2212	0.3904	0.5241	0.6284
4000	0.1709	0.3127	0.4302	0.5276
20,000	0.0368	0.0723	0.1064	0.1392

From the Table 8, total cost of components' maintenance under progressive deterioration, the component with highest probability of failure was the worst scenario, while the maintenance with the least failure probability was termed the best scenario (Table 9). In all the schedules of Table 8 (750, 1500, 2250 and 3000), the preventive policy has a uniformity of cost of N95, 050. In the 750 schedule, the repair policy cost was zero; hence no repair maintenance was required at those cycles. In this schedule, the preventive maintenance policy has the highest cost followed by the replacement maintenance. In the 1500 schedule, the highest cost was recorded in the preventive maintenance, while replacement policy had the least cost. Under the 2250 schedule, the preventive maintained the lead in cost while the repair had the least cost. The same was observed in the 3000 schedule. A steady increase observed in the total cost from the 750 to 3000 schedule (that is N149, 677 to N156, 180.5 and N162, 989.34 to N166, 186.34, respectively).

The replacement maintenance had its least cost fall at the 1500 maintenance schedule. This implied that carrying out replacement maintenance at this schedule would be the most economical (save cost) and less failure prone than waiting until the 3000 maintenance schedule.

Table 8 Total Cost of Maintenance with Respect to Highest Failure Probability

Schedule Policy	**750 (hrs)**	**1500 (hrs)**	**2250 (hrs)**	**3000 (hrs)**
Preventive	95,050	95,050	95,050	95,050
Repair	0	16,458.75	16,499.84	16,499.84
Replacement	54,636.5	4,471.75	51,439.5	54,636.5
Total	149,686.5	156,180.5	162,989.34	166,186.34

In the table 9 the consideration is on the total cumulative cost incurred on the components' maintenance under progressive deterioration with the highest probability of failure (the worst scenario) in place. In the 750 schedule, no repair maintenance was carried out since it had zero value. The highest cost was observed in the preventive maintenance policy, N285, 121.49. In the 1500 maintenance schedule, repair maintenance policy had the least cost, while preventive maintained the highest cost, N570, 300. In the 2250 maintenance schedule, preventive had the highest cost followed by replacement and the least was repair maintenance. The same also occurred in the 3000 schedule. Repair maintenance had the best (minimum) maintenance cost. The best time to carry out the preventive and replacement maintenance was at the 750 cycles.

Table 9 Total Cost of Maintenance under Progressive Deterioration

Schedule/ Policy	**750 (hrs)**	**1500 (hrs)**	**2250 (hrs)**	**3000 (hrs)**
Preventive (N)	285,121.49	570,300	855,400	1,140,600
Repair (N)	0	24,688.13	148,498	49,499.52
Replacement (N)	163,909.5	268,030.5	462,955.5	655,638
Total	449,030.99	863,018.63	1,466,904.1	1,845,737.52

Table 10 indicates the cost of maintenance based on least failure probability. The preventive maintenance policy was expensive but optimized that of progressive deterioration by about 74%. There was no repair maintenance in the 750 schedule while the cost of maintenance increases across the schedules. The most effective cost to maintain was in the 750 schedule.

Table 10 Total Cost of Maintenance under Non-Progressive Deterioration

Schedule/ Policy	750 (hrs)	1500 (hrs)	2250 (hrs)	3000 (hrs)
Preventive (N)	73,844.35	84,214.30	84,499.45	94,812.38
Repair (N)	0.00	1,192.95	1,755.60	2,296.8
Replacement (N)	2,116.00	4,157.25	6,118.00	8,004.00
Total	75,960.35	89,564.5	92,373.05	105,113.18

3.4. Optimality for Maintenance Policies

In Table 11, highest cost was observed in the preventive maintenance policy. There was no repair maintenance in 750 hrs schedule. Throughout the schedules, the preventive maintenance policy had the highest cost followed by replacement maintenance. The least cost was repair maintenance. The highest cost of repair maintenance was observed at the 2250 schedule.

Table 11 Cumulative Cost for Non-Progressive deterioration

Schedule Policy	750 (hrs)	1500 (hrs)	2250 (hrs)	3000 (hrs)
Preventive (N)	221,533.04	505,285.80	760,495.05	1,137,748.50
Repair (N)	0	1,789.43	15,800.40	6,890.40
Replacement (N)	6,348.00	24,943.50	55,062.00	96,048.00
Total (N)	227,881.04	532,018.73	831,357.45	1,240,686.90

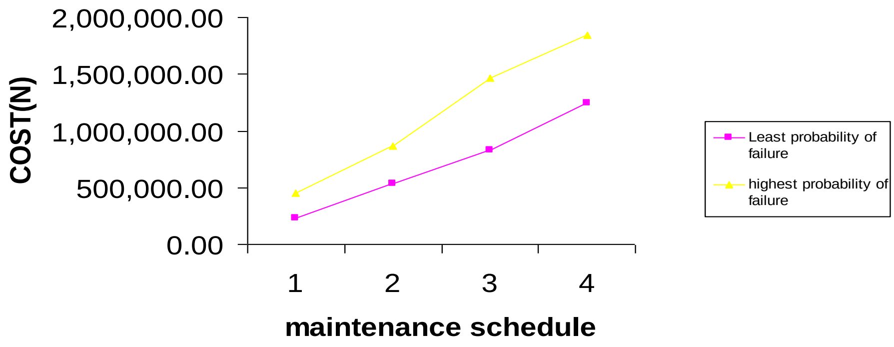

Fig. 2 Cumulative cost of progressive and non-progressive deteriorations

Fig. 2 compares the total cumulative cost on maintenance using the highest and least probabilities of failure. At 750-hour schedule, the total cumulative cost of the highest probability was N449, 030.99 while that of the least probability was

N227, 881.04. There was high disparity of N221, 149.95. This disparity was significant that the surplus can be utilized to solving some other maintenance or administrative problems. In the 1500 schedule, the highest probability has a total of N863, 018.63 while the least probability has N532, 018.73 with difference of N330, 999.90. In the 2250 schedule, the highest probability has N1, 466, 904.10 while the least probability has N831, 357.45, and it defers by N635, 546.65. For the 3000 schedule, the highest probability recorded N1, 845, 737.52. This was about eighteen times the amount used to carry out the total maintenance in the 3000 schedule under the least probability of failure. The highest amount for total cumulative for least probability of failure is N831, 357.45 while that of highest probability is N 1,845,737.52. A lot of money was saved by adopting non-progressive deterioration over progressive.

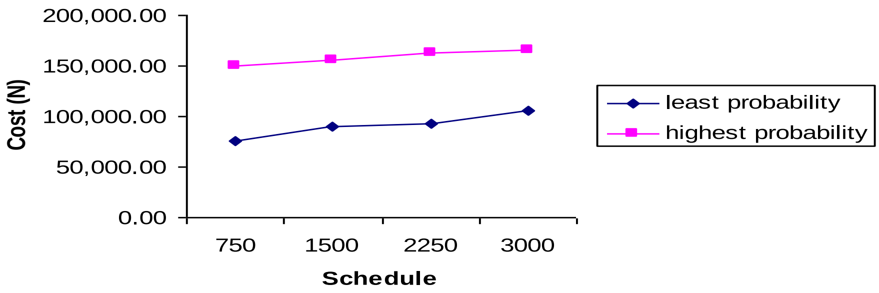

Fig. 3 Cost of components using least and highest probabilities

In comparing the total cost of components with respect to high and least probabilities, there was a remarkable disparity between the total cost of components in Figs. 2 and 3. Therefore, the least probability of failure (non-progressive deterioration) for components was recommended for adoption. There was a significant saving in maintenance cost of components under the non-progressive deterioration. In the 750 schedule, while the cost of maintenance with progressive deterioration was N149, 677, that of non-progressive, least failure probability was N75, 960.35 with savings of 49.25% over the former. Therefore, most economic schedule was 750 cycles. The summary of the differences in the total cost based on least or highest probability of failure was presented by Table 12, from which the highest percentage difference lies with 750-hrs schedule.

Table 12 Difference in total cost based on least or highest probability of failure

Maintenance Schedule/ cost	750 (hrs)	1500 (hrs)	2250 (hrs)	3000 (hrs)

Cost wrt progressive	149, 677	156, 180.50	162, 989.34	166, 186.34
Cost wrt non-progressive	75, 960.35	89, 564.50	92, 373.05	105, 113.18
Difference/ %	73, 716.65 /49.25%	66, 616 /42.65%	70, 616.29 / 43.32%	61,073.16 /36.75%

4. CONCLUSION

Most manufacturing industries all over the world today are experiencing challenges with production in the area of electric power as a significant input for the factor of producing new products. Among these challenges are inadequate maintenance strategies or policies employed to checkmate this negative trend as it affects the totality of the industry on the overhead and general running of the industry if not adequately addressed. The conventional maintenance procedures utilized in the industry can no longer cope with latest and vibrant technological challenges in the areas of components' rebranding and miniaturization. This study has adequately addressed the problem of electric power plant failure through provision of adequate maintenance scheduling method that disallowed component progressive deterioration. The method of continuous or progressive deterioration employed to tackle maintenance problems in the industry will keep machines and power plant operable whenever there was public electric power outage. The maintenance switching strategy provided has solved the problem of operations of the corporation by providing effective guidelines for choosing the best maintenance option(s) that can sustain the prevailing production system. The developed approach can be extended for solving maintenance problem in other production organizations by careful identification of critical components of the plant and their maintenance cycles. The maintenance switching mechanism provided can be applied to minimize maintenance costs. From the results it can be concluded that non-progressive strategy was promising for Corporation's maintenance management. It was the most economic maintenance plan (preventive, repair, or replacement) because of its timely checkmating unplanned sudden damages and high maintenance cost. Study on the effects of changing maintenance environment such as speeds, temperatures and vibration on maintenance cost will be treated in the future.

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BIOGRAPHICAL NOTES

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