Nigerian Research Journal of Engineering and Environmental Sciences 3(2) 2018 pp. 887-897

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

RJEES

Original Research Article

A Preventive Maintenance Model for Electrical Installations in Residential Building Services

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ARTICLE INFORMATION

Article history:
Received 20 July, 2018
Revised 14 October, 2018
Accepted 16 October, 2018
Available online 30 December, 2018

Keywords:
Chem-Rod electrode
Cost
Earthing
Electrical installations
EPM
Residential building services

ABSTRACT

Safety and maintenance costs of electrical installations have become very essential design components in electrical services for residential buildings for decades. As proper maintenance ensures availability and reliability of electrical installations, so also a conscientious electrical preventive maintenance (EPM) programme ensures good performance of electrical equipment in residential buildings. Indeed, the need for preventive maintenance of electrical installations in building services are very essential as cases of severe damages arising from electrical faults abound in any building structure. In this paper, the authors have clearly laid out regular inspection procedures for electrical installations and have developed an EPM model to obtain the optimal number of inspections for electrical installations so as to effectively reduce cost of maintenance, repairs or replacements of electrical installations in the residential building of study. Some general safety procedures leading to safe utilization of electricity in residential building structures are elaborated. The authors have recommended the use of Chem-Rod electrodes for system earthing and have proffered an appropriate EPM work schedule plan for the case study.

1. INTRODUCTION

Since the discovery and development of electricity as a source of power in the 19th century, electrical installation has always been a very important component in building services (Gross, 1979; Okah-Avae, 2003). In building basic infrastructures within the urban settlements, adequate design procedures have to be followed even for the least electrical installation task so as to ensure a reasonable level of availability and reliability. From time to time throughout the lifetime of all electrical installations, breakdown or possible signs of breakdown abound which indicate a call for maintenance. Maintenance has been defined as an accepted and acceptable method of conserving resources (Faluyi, 1992). Maintenance schedule plans often adopted in practice include corrective and preventive maintenance approaches. This paper emphasizes an

EPM approach. It is an approach whereby scheduled work is carried out regularly on electrical installations to forestall any early failures during operation. The focus of this study is to reduce as much as possible the number of system component failures and repairs by an extensive use of a developed EPM model. The EPM program is developed and implemented based on the requirements of: 1) DOE 4330.4B, maintenance management program; 2) NFPA 70B, recommended practice for electrical equipment; 3) National Electrical Testing Association (NETA); and 4) ANSI-C2, National Electrical Safety Code.

Extensive studies on preventive maintenance planning models and techniques (Sortrakul *et al*., 2005) have been carried out with detailed experimentation and documentation. Some previous studies are presented in literatures (Au-Yong et at., 2014; Wang and Lin 2011; Yeh et al., 2011; Todinav, 2007; Rahim and Ben-Daya, 1998) where preventive maintenance models were developed based on reliability and cost constraints.

In Nigeria, majority of residential and commercial building owners have no EPM work schedule plans for their electrical installation (Faluyi, 1992). Consequently, the overall maintenance costs due to failures of electrical equipment and wiring installations in building services are relatively high in the country. It has become very worrisome that most building infrastructures in the urban settlements have become unsafe to use due to the sparsely implemented maintenance work schedules on their electrical installations. It has become a common occurrence for fire outbreaks on building structures owing to severe electrical faults. In most buildings, loose electrical wiring constitutes a potential hazard to occupants and visitors alike. Cases of infrastructural damage and injuries due to severe electrical faults are abound in the country almost on a daily basis. Quite a number of these incidences would have been averted if building owners adopted proper preventive maintenance work schedules on their electrical installations.

2. METHODOLOGY

2.1. Inspection Optimization Model

The EPM model type for this study provides a systematic inspection and detection of component parts for system's prevention or protection from failures during operating conditions. In this study, the Inspection Optimization Model to calculate the approximate numbers of optimal maintenance inspections per system per unit of time was employed. The systems' (each comprising a given set of electrical installations) downtimes were defined generally by Equation (1) (Dhillon, 2002).

$$DT_{j\,total} = \left(n_j T_i + \frac{C_j T_f}{n_j}\right) \quad (1)$$

Where:
$DT_{j\,total}$ = total downtime for the jth system (per unit of time)
C_j = a constant associated with the jth system
T_f = system downtime due to breakdown or failure
T_i = system downtime due to inspection
n_j = number of inspections for the jth system (per unit of time)

Differentiating Equation (1) and setting the result to zero, yields the optimum number of inspections for a system per unit of time shown in Equation (2).

$$n_j^* = \sqrt{\frac{C_j \times T_f}{T_i}} \quad (2)$$

Where n_j^* = optimum number of inspections for the jth system (per unit of time).

Substituting Equation (2) into Equation (1) yields:

$$DT_j{}^*{}_{total} = 2\sqrt{(C_j \times T_i T_f)} \quad (3)$$

Where:
$DT_j{}^*{}_{total}$ = total optimal downtime for the jth system (per unit of time).

The entire system's downtime of the electrical installation is given by equation (4) as:

$$DT^*{}_{total} = \sum_{j=1}^{N} \left(DT_j{}^*{}_{total} \right) \quad (4)$$

Where:
$DT^*{}_{total}$ = total optimal downtime for the entire system (per unit of time)
N = number of systems
j = the jth system

3. CASE STUDY

Breakdown and inspection records over a one-year planning period for a residential apartment in was used to obtain a preventive maintenance inspection schedule for the various electrical installations. The electrical installation works were divided into five major systems, each system comprising the various electrical devices that make up the system (see Table 1). Records of all inspections, tests, and servicing in accordance with the manufacturer's recommendations and instructions for the local operating environment of the various electrical components for each system were documented for a period of one year. Table 1 shows records of downtime periods of the various components due to failures and inspections from January to December 2014. In the next section, full maintenance guide details in line with standards and manufacturers' recommendations are extensively highlighted for each system of the entire electrical installation work.

4. SYSTEM MAINTENANCE GUIDES

4.1. System (1): Switch Gears

This involves the maintenance of line fuses, changeover switches, distribution boards, earth leakage circuit breakers (ELCBs), miniature circuit breakers (MCBs) and mains cut-out fuses.

4.1.1. Line fuses (generally referred to as control switches)

- Ascertain the general tidiness within and outside of the enclosure.
- Check for loose conductor connections and retighten as needed.
- Lubricate the moveable contact carriage if now stiff.
- Check for signs of arching and discover the cause where noticed.

{If due to partial contact arising from loose connections, act as in second procedure above; If due to weak or impaired insulation, apply tape or varnish as necessary;

If due to partial contact arising from expanded stationary contact gap, adjust the latter accordingly for perfect engagement with the moving contact finger}.

- Confirm that the earthing lead is perfectly in place
- Confirm all fuses are properly seated in their holders.

Table 1: Downtime records of system components for a one-year planning period of the case study (January – December 2017)

System	Components	Downtime due to component failures, T_f ($\times 10^{-6}$ years)	Downtime due to component inspections, T_i ($\times 10^{-6}$ years)
1	Switch Gears Line fuses	3.0	9.0
	Changeover switches	3.0	15.0
	Distribution boards (DBs)	0.0	3.0
	ELCBs and MCBs	15.0	45.0
	Mains cut-out fuses	9.0	18.0
	Total	30.0	90.0
2	Final Sub-circuits Conductors and wiring installations	2.0	9.0
	Junction boxes	0.0	1.0
	Lighting sub-circuits	3.0	1.0
	Ceiling fan sub-circuits	3.0	1.0
	Socket outlet (13- and 15-amps) sub-circuits	5.0	1.0
	Electric Cooker sub-circuit	2.0	8.0
	Electric Water Heater sub-circuits	5.0	9.0
	Total	20.0	30.0
3	Earthing System	20.0	30.0
4	Lightning Arrester	9.0	60.0
5	Permanently connected loads Air conditioners	2.0	5.0
	Ceiling Fans	2.0	5.0
	Electric Water Heaters	2.0	15.0
	Electric Cooker	1.0	8.0
	Electric Door Bell	1.0	2.0
	Fridge/Deep-freezer	1.0	1.0
	Washing Machine	1.0	2.0
	Total	10.0	40.0
	Grand total (T_f, T_i)	89.0	250.0

4.1.2. Changeover switches

The preventive maintenance (PM) procedures are as in the first to fifth procedures of subsection 4.1.1 above.

4.1.3. Distribution boards

In addition to the first, second, fourth, and fifth procedures of subsection 4.1.1:

- Confirm the make-and-break functionality of the MCBs.
- Change MCBs if tripping free (it may be the cause of some socket-outlets not having supply power).

- For the fuse type, check the porcelain holders for cracks. Repair or replace holders if badly cracked.

4.1.4. Earth leakage circuit breakers (ELCBs) and miniature circuit breakers (MCBs)

Besides the fifth procedure of subsection 4.1.1, test for functionality by means of the trip-test knob. Service or change ELCB/MCB if it cannot trip.

4.1.5. Mains cut-out fuses

In addition to the second and fourth procedures of subsection 4.1.1,

- Check where there is partial contact due to the condition of the moveable contact fingers, amend and/or adjust as necessary for perfect engagement with the stationary contact grooves. Replace fuses if incessant arcing is noticed.

- Check fuse-link for signs of overheating. Upgrade fuse if necessary.

4.2. System (2): Final Sub-Circuits

For surface (non-conduit) or partial-conduit wiring designs, the approach is shown in the following subsections.

4.2.1. Junction boxes

Check Junction Boxes for loose connections owing to previous repairs or maintenance work. Retighten connections and properly arrange conductors as appropriate. Repair cracked covers with quality glue or change as the case may warrant.

4.2.2. Lighting final sub-circuits

- Check the condition of the ceiling roses and the connecting flex. Repair or replace patterns and/or cover as necessary.
- Check the condition of pendent lamp-holders and fluorescent fittings. Replace aged and cracked lamp-holders. Replace humming chokes in fluorescent fittings. Replace starter if lamp glows white at both ends and cannot start up. Or, if lamp only flickers but will not start.
- Check the condition of the lamp switches. Mend cracks with glue. Confirm that their make-and-break operations are possible with relative ease. Service or replace switch if operating with difficulty.

4.2.3. Ceiling fan final sub-circuits

- Check as in the first procedure of subsection 4.2.2
- Check the condition of regulators. Change regulators if noisy. Repair or replace regulator if the regulation mechanism has now malfunctioned.
- Check the condition of the ceiling fan suspension pipe bushing. Replace if badly worn out.

4.2.4. Socket outlet final sub-circuits (13- and 15-Amps)

- Check the condition of the power receptacles. Replace seriously cracked receptacles. Where contact apertures show signs of arc-burn, necessary repairs for perfect contact with plugs should be done; otherwise, receptacle should be replaced completely.

- Ensure that the ring final sub-circuit conductor/cable (as applicable) returns, and is perfectly connected to the fuse or MCB from which it originated.

4.2.5. Electric cooker unit final sub-circuit

Ensure that the cooker control unit make-and-break operation of the MCB functions with relative ease.

4.2.6. Electric water heater final sub-circuit

Check that the heater control unit switching and protecting devices are in good operating condition.

4.2.7. Conductors and wiring installation checks

Check Conductors/cable thrown over the ceiling for signs of caking and brittleness. Apply varnish in the affected areas or change conductors/cable wholly or partially as necessary. In general, check to ensure that the earth-continuity conductor reaches every loading and switching point for each final sub-circuit, and run perfectly right from the distribution board. The use of test lamp can make things a lot easier in this regard. Also, ascertain that the insulation resistance is not below 1MΩ with a $500V_{dc}$ Mega-tester (Neidle, 1975) at $28^{o}C$ for one minute. For full-conduit and partial-conduit wiring designs, it is proper to do the following:

- Check to ascertain that the continuity of the metallic conduit pipes all through the installation is intact by use of test lamp as may be necessary.
- Check carefully and discover the faulted final sub-circuit causing shocking floors and effect necessary repairs.
- Check final sub-circuit loading and switching points as in the case of surface designs mentioned in subsection 4.2.1

4.3. System (3): Earthing System

The earthing system comprises essentially the earthing leads, rods or electrode with associated clamps, and the general mass of the earth. Here, it will be required to:

- Check the condition of the earthing lead connection to the distribution boards, switches, changeover switches or the ELCB. Loose connections should be made good. Rusted connecting point be wire-brushed, coated with Vaseline and retightened.
- Check the exposed portion of the earthing lead for kinks and serious defects. Straighten and tape or replace same as need may demand.
- Excavate and reveal the earthing lead/rod clamping point and check for signs of corrosion. Treat corroded or rusted contacts.
- Confirm the earth electrode-to-ground resistance is in range.

Generally, the earth resistance should not be more than 5Ω (Uppal, 1981). However, up to 10Ω is tolerable in the country for this purpose (NEPA, 1977). Thus, if found beyond 10Ω, the resistance should be improved using carbon dust, common salt or other chemicals like magnesium sulphate, copper sulphate and calcium chloride together with water (Enyong, 2001).

Table 2: Comparing *Chem-Rod* electrode performance to other grounding electrodes in varying soil and weather conditions over a three year period (Product Group, 2015)

Electrode Type	Soil resistivity of test sites (Ω-m)					Performance variance as a result of moisture/Temp. (%)
	9	6.2	270	270k	30k	
	Measured resistance (Ω)					
Copper, Clad rod*	7.2	>22	65	430	10k	250
Rod in conditioned soil (1st year)*	2.3	1.8	44	350	1.5k	200
(3rd year)*	5.0	30	>80	400	3k	200
Air breathing rod*	0.5	9.0	22	240	2k	200
Chem-Rod 2.5/8''x10'	0.2	<2.0	<10	<90	<1k	40

*Conventional ¾" x 10' rod

Also, a type of earthing rod known as *Chem-Rod* electrode is preferable for good earthing purposes. It is an extra efficient low surge-impedance, chemically-activated grounding electrode which continually conditions the surrounding soil, and making the soil more conductive. With a diameter of 64.3mm, i.e. greater surface area and greater contact with the earth soil, one *Chem-Rod* electrode has the equivalent performance of 15 to 20 conventional earthing rods (Enyong, 2001). Table 2 compares *Chem-Rod* electrode performance to other grounding electrodes in varying soil and weather conditions over a three-year period. From the Table, it is shown that *Chem-Rod* electrodes has the lowest resistance values and that their performance varied the least. In summary, *Chem-Rod* electrodes are stable, efficient and at least five times more reliable than other conventional rods. Figure 1 shows a vertically installed *Chem-Rod* electrode where the soil is easy to dig.

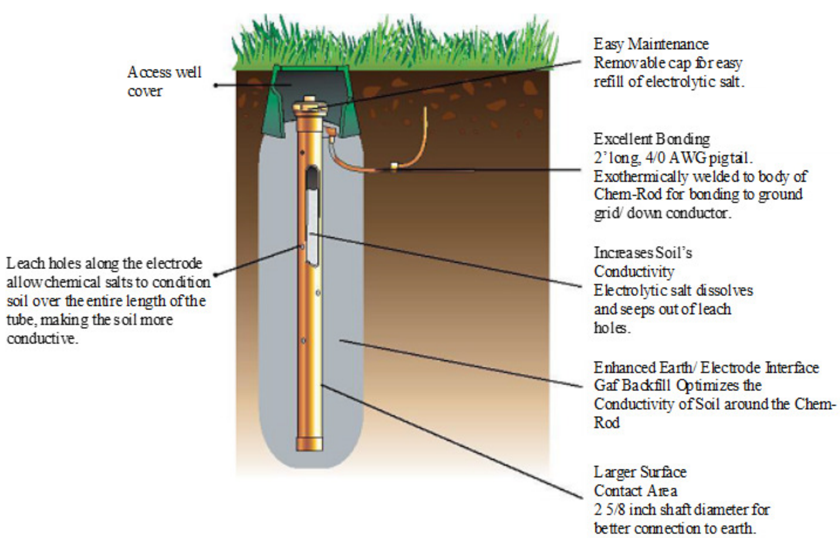

Figure 1: Vertical *Chem-Rod* electrode installation (CHEM-ROD, 2015).

4.4. System (4): Lightning Arrester

This can be accomplished as mentioned here:

- Check the air-terminal (for spikes or whatever) and ensure that it is well seated erect in place. Adjust as may be required if otherwise.
- Check the earthing strip connection to the air-terminal. Make same seated erect in place. Adjust as may be required if otherwise.
- Check and treat the earthing strip for signs of rusting as earlier discussed in section 4.3.
- Check and treat the earthing rod clamping point/electrode-to-ground resistance as earlier discussed.

4.5. System (5): Permanently Connected Electrical Loads

The permanently connected and maintainable electrical loads for standard residential buildings include the ceiling fans, electric water heaters, air-conditioners, electric cookers, electric door bells, fridges/deep-freezers and washing machines.

4.5.1. Ceiling fans

- Clean up the fan blades if dirty or dusty.
- Lubricate the motor bearings with grease if observed to dry up.
- Check for signs of roof leakage directly above the motor. Rectify leakage to avoid ingress of water into motor windings.
- Test and record the insulation resistance of the windings. This should not be less than 0.5MΩ with a $500V_{dc}$ Mega-tester (Neidle, 1975) at 28°C for one minute. Dry winding in oven if too damp.

4.5.2. Electric water heaters

In addition to ensuring tidiness, check the condition of the heating element. Ensure that it is sufficiently off the ground and electrically continuous, using the testing approach in the last procedure of subsection 4.5.1.

4.5.3. Air conditioners

Besides general tidiness and particularly of the condensing unit to be confirmed,

- Check the condition of the supply lead/plug. Change plug if signs of burns are seen around pins. Repair lead where insulation is seen to have been impaired.
- Check relay contacts for pitting or burns, which will result in poor conduction and inability of the compressor-motor to start (Lamere, 1981). Replace same if need arises. Maintain the entire starting and running system involving the capacitors.
- Ascertain that the compressor and the fan/blower motors operate freely. Get them serviced if their bearings are suspected sticky or dry.
- Ascertain that the fan blades do not rub against the guard.
- Test and record the insulation resistance of the motor winnings. Access results as in the last procedure of subsection 4.5.1.

4.5.4. Electric cookers

In addition to the actions of the first procedure of subsection 4.5.3, check for loose or broken flex connections. Retighten or renew connections as appropriate.

4.5.5. Electric door bells

- Remove dirt that may have gathered on the gong.
- Confirm that the supply lead makes good contact at bell push battery or transformer.
- Check and confirm that the magnetic core is not noisy.

4.5.6. Fridges/deep-freezers

Check as in the case of air-conditioners (subsection 4.5.3).

4.5.7. Washing machines

- Check for loose connections at the 13A input plug terminal or at the equipment end if power comes on intermittently. Retighten the flex accordingly if seen to be loose.
- Treat motor as in the second and last procedures of subsection 4.5.1.
- Check belts for slackness. Restore belt tension as appropriate.
- Check machine for leakage. Repair hose, change pump gasket, etc. as required.
- Check the brake cable/lining for weakness, wear and tear. Adjust or fit new cable as may be required. Fit new lining if the one in place is worn out.
- Check the condition of the heating element as in subsection 4.5.2.

5. SAFETY RULES AND PRECAUTIONARY MEASURES

5.1. Against Fire Outbreak

- Always ensure that fuses of the correct rating are used. Every plug has a 13A fuse. Always check the amperage of the device to which it is to be connected, and fit the right fuse before using the plug.
- Avoid the danger of overloading a radial final sub-circuit by using adaptors on a power socket. Where necessary make provision for an extra socket to be fitted by a qualified electrician.
- Do not use electric heater without a guard over the bars. A fire can be started if clothing or any other combustible material comes in contact with the heating element.
- Take care in using extension cords for the supply of apparatus due to fire hazard it can pose. Note that the flex frays with time and use, hence, the need for regular inspections. More so, with synthetic wall-to-wall carpeting in many homes, which is easily ignited and made to smoke.
- Every home should have at least one portable fire extinguisher to be tested quarterly for functionality and recharged as soon as exhausted.

5.2. Against Electric Shock

- Ensure that apparatus with a three-core flex is properly earthed.
- Do not touch the metal parts of an electrical equipment with wet hands; more so, make wet contacts with earthed pipes or taps (e.g. the pipes to the electric water heater).
- Note that the flexible cords can cause shock if sufficient care is not exercised to terminal points.

- Take care to always connect the right wires to the right terminal point. Equipment connected wrongly (i.e. live wire to neutral point and vice versa) can function correctly when switched "ON" but can pose danger even when switched "OFF" (Reader's Digest, 1972).
- Observe the 2-meter rule strictly in the installation wiring of socket-outlets in the same room to be supplied by different phases (Francis, 1971). However, this applies more frequently to non-domestic premises.
- For maximum safety, always use sleeved plugs having pins coated in insulting materials.

6. RESULTS AND DISCUSSIONS

Based on records taken for downtimes over a one-year period at the case study location, system 4 recorded the least downtime of approximately 5 minutes due to component failures, and System 1 recorded the highest downtime of approximately 47 minutes due to inspections. Downtimes of approximately 47 minutes and 131 minutes of the study year due to component failures and inspections respectively, were obtained for the entire electrical system. The optimal number of inspections obtained for System 4 is not feasible for a yearly inspection period (since $n_4{}^* < 1$), but feasible for a three-year inspection period with an approximate number of one inspection in every three years (i.e.$n_4{}^* = 0.99$). A total optimal downtime of 5 hours for the entire electrical system of the study year was calculated using Equation (4).

The optimum number of inspections per system as obtained from the study has shown a possible reduction in the total costs of electrical component maintenance and repairs or replacements for each system, and as such, the EPM schedule developed in this study is economically implementable when compared to frequent inspection times prescribed by the manufacturers.

The earthing system (i.e. System 3 in this study) is the most versatile and essential electrical component in any building services design. A building structure without an efficient and reliable earthing system in place can pose serious dangers to the structure itself and the users. Hence, Table 2 has shown to give priority to the use of *Chem-Rod* electrodes for earthing purposes; and these electrodes also play a vital role in lightning arresters to ensure increased overall system reliability of the entire electrical installation work. Also, an overall reduction in the costs of maintenance, repairs or replacements of electrical components is expected in this regard.

7. CONCLUSION

Life has no duplicate and when lost it is irretrievable. Thus, whatever is capable of posing a danger to life and property alike should be handled with utmost care. Electrical installations being one of such danger posing component in building services, require proper attention. The objective has been that of creating the necessary awareness as to the relevance and need for conscientious preventive maintenance policy to be adopted and pursued vigorously by all building owners for continued healthiness, functionality and safe use of building facilities. The authors have firstly, been able to outline the basic preventive maintenance procedures with a view to maintaining a consistent level of maintenance and a reduced cost of repairs or replacements of electrical installations. Secondly, the authors have developed an optimal EPM programme schedule that tends to reduce maintenance costs and failure rates of electrical installations in residential buildings.

8. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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