Optimum Mix of Ground Electrodes and Conductive Backfills to Achieve a Low Ground Resistance

George Eduful, Joseph Ekow Cole and P.Y. Okyere

Abstract— **Based on response curves derived from field measurements, optimum number of vertical ground electrodes for grounding electrical installation is determined. On sites where the optimum number of the electrodes cannot reach a target ground resistance, a 'critical resistance area concept' with conductive backfills is used. In this study, efficiencies of local conductive backfills for reducing ground resistance are investigated. Results show that application of tyre ashes as a conductive backfills lowers ground resistance to over 80%. It is also shown that the most favourable benefit in the ground resistance improvement is to limit the backfill to 66% of the total number of ground electrodes installed.**

Index Terms: **Ground electrodes, Ground resistance, Conductive Backfills and Critical Resistance area.**

I. INTRODUCTION

"Grounding" may be described as connections to the general mass of earth. The term is used interchangeable with the term earthing. Grounding is used for a number of good reasons; primary among them are personnel and equipment safety. Personnel safety is provided by low resistance grounding and bonding between equipment enclosures so that currents, due to faults or lightning, do not result in voltages sufficient to cause a shock hazard. In relation to equipment safety, low resistance grounding and bonding prevents build -up of static charges that could result in electrical discharge in potentially hazardous environment.

Low earth resistance is essential to meet electrical safety standards. The resistance figure can vary from 10 ohms for lightning protection to below 0.1 ohm for many sites where protective devices must operate in a very short time due to the large fault currents involved [1]-[4]. According to the IEEE Green Book [5], the grounding electrode resistance of large electrical substations should be 1 Ohm or less.

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For commercial and industrial substations the recommended ground resistance is 2-5 Ohms or less.

The resistance figures also vary from industry to industry. Telecommunication industry has often used 5 ohms or less and certain Utility Companies use 10 ohms or less for high voltage distribution substations and 1 ohm or less for low voltage distribution substations [6, 7].

A resistance to ground of 25 ohms or less for a single electrode is specified [8] [9]. However in practice, it is seldom that a single electrode can provide a low resistance enough . Some standards [10] and in reference to Fig-1, also specify 5 electrodes as the optimum number to reach a target resistance. Where the target resistance is not reached, supplementary grounds electrodes are added. It is shown in this study that there is a limit to number of supplementary electrodes that could be used in relation to the degree of earth resistance improvement expected. As more ground electrodes are used, percentage reduction in resistance for each additional electrode becomes exponentially less. As a result, it becomes economically unwise to drive more electrodes into the ground for a target resistance.

Chemical treatment and other methods are also available. The use of chemically activated grounding electrode is known [11]. However, in a study to determine the most effective method of installing low resistive ground electrode, majority of the standard methods were rejected for practicality or cost reasons [8]. Also, little information and discussion has been focused on the optimum mix of ground electrodes and conductive backfills require to reach a desirable ground resistance.

In this study, efficiencies of local conductive backfills for reducing ground resistance are investigated. Results show that application of tyre ashes as a conductive backfills lowers ground resistance to over 80%. It is also shown that it is more economical to limit the conductive backfills to about 66% of the total number of ground electrodes installed for an optimum degree of ground resistance improvement than to backfill the entire installed electrodes.

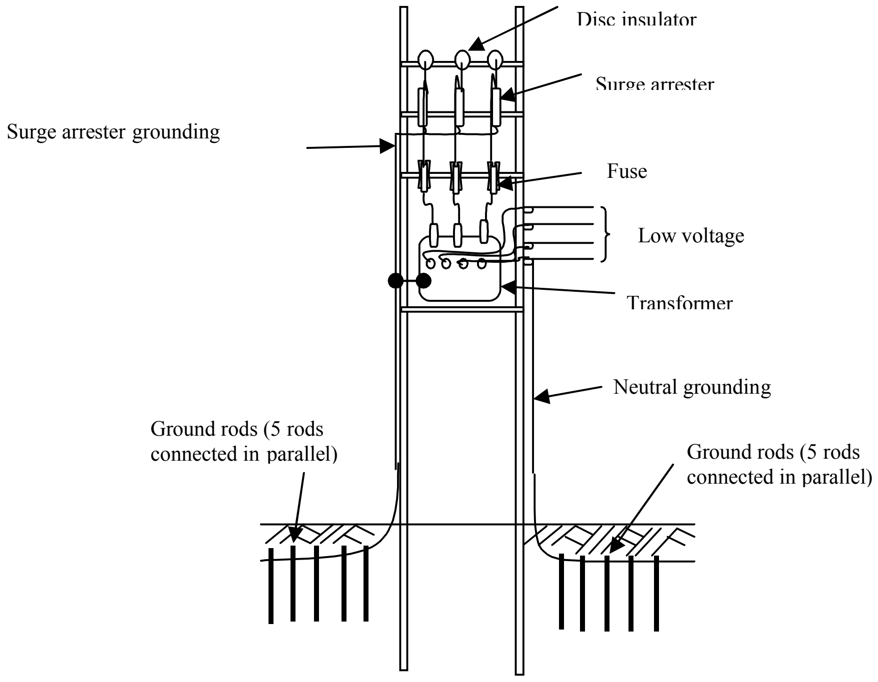

Figure-1: Grounding of Pole Mounted Transformer

II. Theory of the Critical Resistance Area Concept

On sites where soil resistivity is high, a number of techniques are used to lower high ground resistance values. Critical resistance area concept is ground resistance-reducing technique proposed in [12]. At a constant resistivity, analytical formula for ground electrode resistance in terms of distance *x* from the electrode is obtained in [11]. This is given as

$$R(x) = \frac{\rho}{2\pi l} \ln\left[\left(\frac{r+l}{r}\right)\left(\frac{x}{x+l}\right)\right] \qquad (1)$$

Where, *p* is the soil resistivity in ohm-meter, *l* length of the electrode in meters, *r* radius of electrode in meters.

Using equation (1), graphs were plotted for three ground rods of different length, see Fig-1.

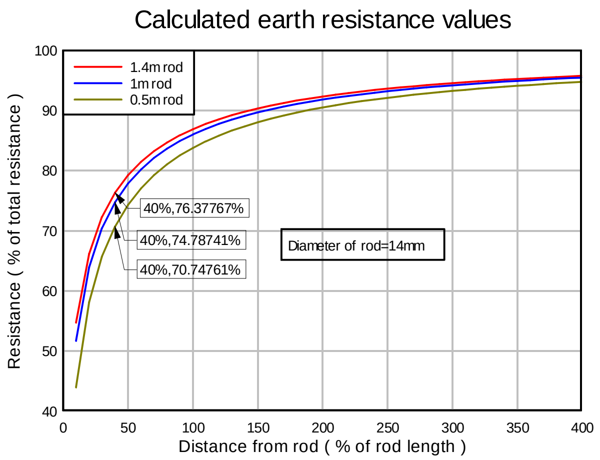

Fig-1: Variation of ground resistance with distance from ground electrodes

It was observed from the graph that the resistance curves begin to saturate around 40% distance from the electrodes. At this distance, about 70% of the ground resistance was obtained. Thus the 40% distance became the critical radius. This radius was used as critical resistance radius for the study.

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III INVESTIGATION PROCEDURE

DETERMINING THE OPTIMUM NUMBER OF GROUND ELECTRODES

Vertical ground electrodes of 1.2-m and 30-cm length of each 14mm diameter were employed. Eight numbers of 1.2-m electrodes, separated at intervals of 220% of the electrode length, were driven into soils of different resistivities and in turns connected in parallel. At the same sites not far from the 1.2-m electrodes, the 30-cm electrodes were also installed. In each case (for the 1.2-m and the 30-cm electrodes) corresponding ground resistance measurement were taken, as the electrodes were being connected in turns. Ground resistance values were recorded using the DET5/4R Digital Earth Tester applying the Fall-of –Potential method or the so-called "62%" rule [13] [14].

EXAMINING EFFICIENCIES OF CONDUCTIVE BACKFILLS

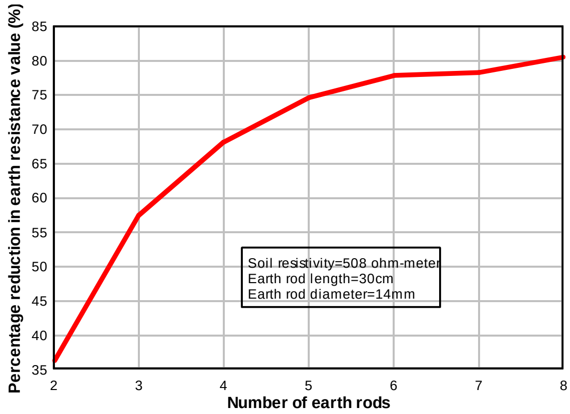
To determine the most effective local conductive backfills to complement the optimum number of ground electrodes in order to reach a desirable ground resistance value, electrical and chemical properties of four conductive backfills namely Palm Kernel Oil Cage, Tyre ashe, Wood ashe and Powdered cocoa shells were investigated. For the purpose of comparison an earth rod without a conductive backfill termed reference electrode was also installed at the site.

Ground electrode of 30-cm length and 14mm diameter were installed using the respective conductive materials as backfills. Three different sites of different soil resistivities were selected. Ground resistances of the electrodes with the conductive backfills were monitored in a very dry season for a period of four months and their respective efficiencies compared with the reference electrode.

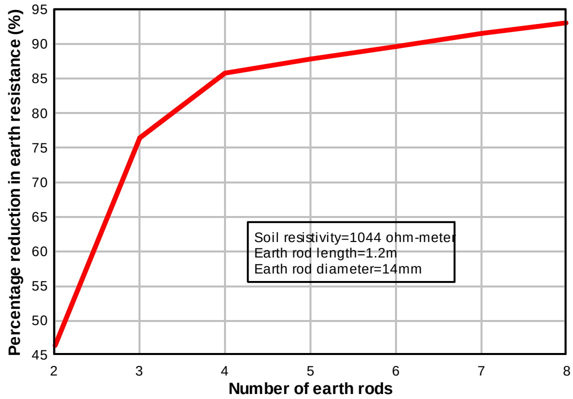
Chemical properties of the samples were tested at a Soil Research Institute. Parameters tested for are: moisture holding capacity and pH level. Ionic concentrations of the samples which includes; sodium, potassium, and magnesium were also examined. Examination of the pH level was to ensure that the conductive materials are environmental friendly and are not inimical to the ground electrodes in terms of corrosion

IV RESULTS AND DISCUSSION

Fig-2 represent response curve of multiple ground electrodes connected in parallel. It was observed that significant percentage reduction in ground resistance is noticeable on 2nd, 3rd, and the 4th electrodes. In Fig 2(a), up to about 70% reduction was obtained on the 4th electrode. The response of the 30-cm electrode is almost in agreement with the 1.2-m electrodes which also indicate a total reduction of 85% on the 4th rod. It is noted that the percentage reduction in the earth resistance value begins to saturate from the 5th electrode. This finding validates the standard in [6] where 5 electrodes are specified for grounding electrical installation. Where a desirable ground resistance was not reached after the 5th electrode, conductive backfills were considered.



(a)



(b)

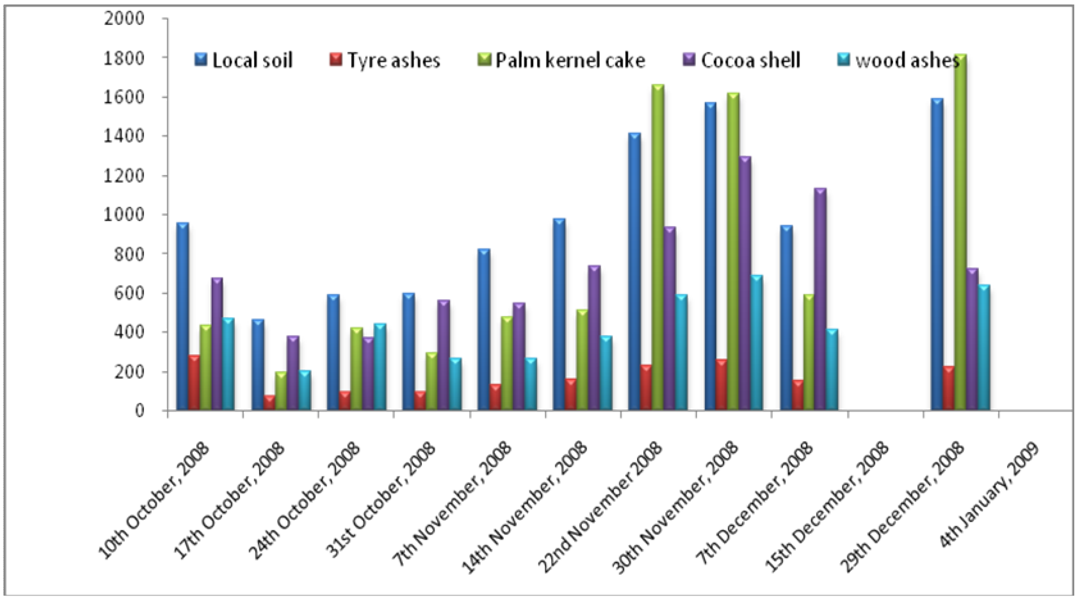
Fig-2: Response curve of ground electrodes connected in parallel

Fig-3 compares efficiencies of four conductive materials used as ground electrode backfills to a driven electrode without a conductive backfills. For clarity, 15th December 2008 and 4th January 2009 results, which recorded extremely high resistance values were taken out of Fig-3(a) and plotted as Fig-3(b). All the backfills, compared with the local soil, offered certain amount of reduction from 10th October through to 14th November, with tyre ashe providing significant and stable degree of reduction over the period; a variation of 5% in resistance value during the period was observed. However, interesting results were noted from 22nd November to 4th January, 2009. The Palm Kernel Oil Cake [PKOC] and Powdered Cocoa Shell PCS] registered a resistance value higher than the local soil.

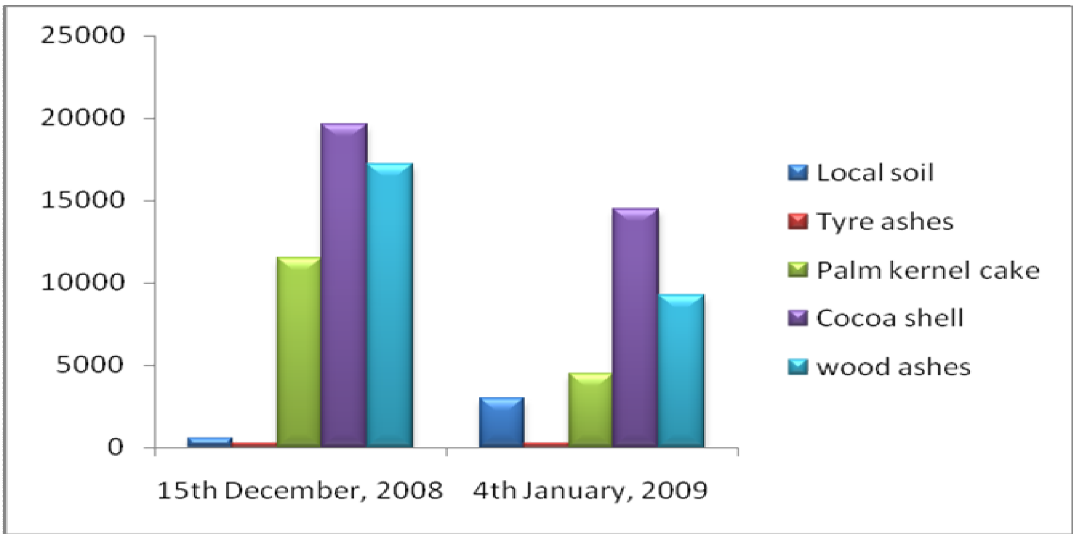
However from 22nd November, 2008 through 4th January, 2009 when the dry season set in, their resistances became very unstable, falling when there were light rains and soaring when there were no rains. There were days as shown in Figure 1.b when they produced resistance values many times greater than that of the reference electrode. These materials shown to have high water-holding capacity are found to be effective in wet weather conditions and ineffective in a very dry weather conditions. The wood ash though relatively more stable was also ineffective in the dry weather conditions. These three materials could be of interest where earth electrode could be installed deep enough to reach the water table.
Soils have a pH range of 5-8 [15]. The pH level of the tyre ash is found to be within this range. In this range, pH is generally

Table-1: Samples and result of parameter tested

Samples / Parameters	PKOC	PCS	Tyre Ashe	Wood Ashe
Carbon (%)	45.79	45.94	31.63	43.16
Sodium (ppm)	674	230	1098	4850
Potassium (ppm)	4010	16514	3538	22638
pH	4.51	4.25	6.22	8.99
Moisture holding capacity	102.35	337.52	70.59	17.96



(a)

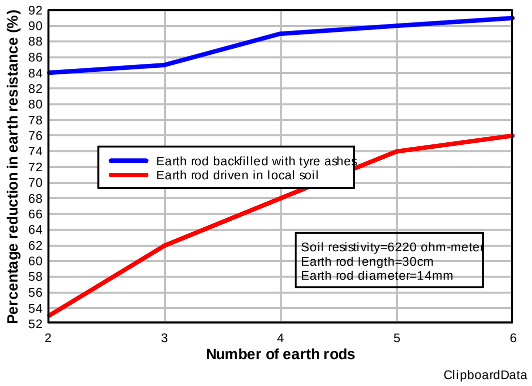


(b)

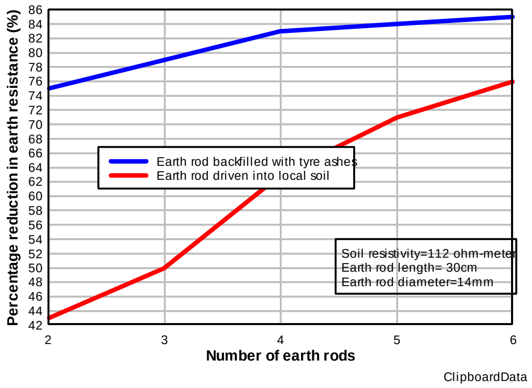
Fig-3: Comparing efficiencies of local materials not considered to be the dominant variable affecting corrosion rates. The pH levels of the three others though outside the range are very close.

Considering the ground resistance-reducing effect of the tyre ashe, its stability over the period under study and relatively low acidic content, it was selected as the most effective conductive backfills for augmenting the performance of multiple grounds.

Fig-4 compares response curves of electrodes installed without a conductive backfills and ones installed with tyre ashes as a backfill at two different sites. The efficiency of the tyre is very significant. Whilst the reduction in relation to the local soil on the 6th electrode [Fig (a)] is about 76%, only two electrodes from the tyres ashes gave a reduction of 84%.This suggest that even more than six electrodes installed in a local soil will not be equal to two electrodes backfilled with tyre ashes. It is also observed [Fig (a)] that whereas the tyre ashes curve begins to saturate from the 4th rod with 89% reduction in ground resistance, the local soil resistance curve saturates from the 5th electrode with 74% reduction; an indication that it is not economical to backfill more than four electrodes with a conductive material.



(a)



(b)

Fig-4: Response curves of electrodes installed without a conductive backfills and ones installed with tyre ashes as a backfill

However, in order to validate the above hypothesis, six vertical electrodes were installed in a local soil and the total resistance noted. Subsequently, the tyre ashes were applied as a backfill to the electrodes in turns noting the results. As shown in Fig-5, four electrodes were backfilled keeping in circuits other two electrodes without a backfill. The result showed over 80% reduction relative to the total resistance (without a backfills). Backfilling the rest of the two electrodes did not yield any significant reductions. Thus it became evident that the most effective number of electrode backfill is to limit the backfills to four electrodes, representing 66% of the total number of electrodes installed, beyond which resistance improvement is insignificant.

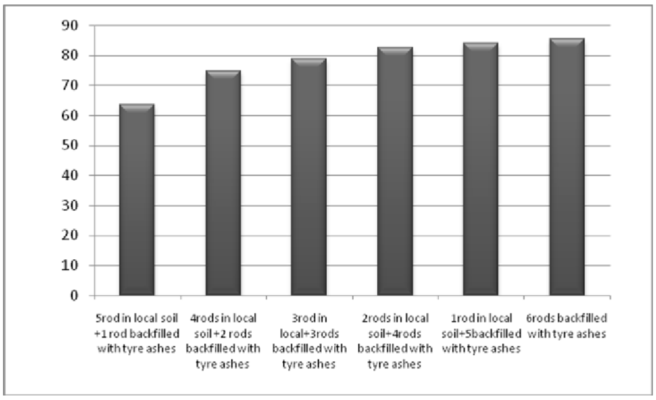


Fig-5: Combining electrodes with and without a conductive backfills

V. CONCLUSION

Based on response curve derived from field measurements, optimum number of vertical ground electrodes is determined. The findings validate a standard where 5 electrodes are recommended for grounding an electrical installation. Where a target resistance is not reach, an efficient conductive backfills such as tyre ashes is recommended applying the critical resistance area concept. For optimum result, the backfill should be limited to 66% of the total number of electrode installed.

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