

RESEARCH ARTICLE

Assessment and prediction of earthing resistance in domestic installation

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Before the introduction of the Ghana Electrical Wiring Regulations 2012 (L.I. 2008), most residential wiring within Sunyani Municipality was carried out by unlicensed artisans. This situation imposed a need to investigate the effectiveness of the earthing systems carried in the Sunyani municipality. Therefore, the current study sought to evaluate earthing resistance effectiveness within the Sunyani Municipality by measuring the earthing resistance of 1004 homes with an earthing resistance tester from January 2016 to April 2018. Again, we predict future resistance based on measured values. Out of 1004 buildings surveyed, 834 had an earthing system in place. Twenty-eight buildings, recorded an earth electrode test within 0.0 to 10 Ω representing 3.36%. A high percentage (96.64%) had their earth electrode resistance above the acceptable value by the Energy Commission of Ghana. The results revealed that the overall effectiveness of earthing in the domestic installation in Sunyani Municipality is below average compared with Ghana Energy Commission benchmark.

KEYWORDS

earth-electrode, earthing, earthing-lead, earthing-resistance, soil-resistivity, earthing-conductor

1 | INTRODUCTION

Faults associated with electrical and electronic systems are inevitable; therefore, every electrical or electronic appliance, equipment or system must be grounded or earthed. Earthing provides a low resistance path for dissipating fault current into the general mass of the earth,¹ which ensures safe operation of electrical and electronic installations in domestic settings. Additionally, earthing plays a critical role in ensuring the general well-being of generation, transmission, and distribution of electrical energy systems.

In recognition of the benefits associated with earthing, it is mandatory in various countries to provide earthing in both domestic and industrial installations. Recently, a limited number of papers have sought to assess the effectiveness of earthing systems. Raizer, Valente Jr. and Coelho proposed a method for measurement of earth resistance, touch and step voltage with urban areas.² Jiaolong and Yunfeng proposed an improved method for measuring transmission line tower grounding resistance.³ Talat, Farahat, and Osman presented a new mathematical model for calculating the grounding resistance of wind turbines in various soil types.⁴ Ilenin et al proposed a technique for designing power station earthing system.⁵ Likewise, Valente et al performed an investigation of several analytical and numerical prediction methods for finding the impedance of earthing system in power substations according to the Fall-of-Potential technique.⁶

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Although some amount of research work has been reported concerning earthing systems, very little has been done to assess the effectiveness of domestic earthing systems. To the best of our knowledge, in the particular case of Ghana, no research aimed at assessing the effectiveness of earthing systems in domestic settings has been reported. This research, therefore, takes up the initiative of assessing the effectiveness of earthing systems in Ghana using Sunyani Municipality as a study area. Sunyani is the administrative capital of the Bono Region of Ghana. Sunyani is a municipality, and it is one of the 29 administrative districts. Its location is between latitudes $70^{\circ} 20'N$ and $70^{\circ} 05'N$ and longitudes $20^{\circ} 30'W$ and $20^{\circ} 10'W$.⁷

Before the introduction of the Ghana Electrical Wiring Regulations 2012 (L.I. 2008),⁸ many residential wiring within Sunyani Municipality were carried out by unlicensed artisans. A visual inspection of the residential installations by these unlicensed technicians reveal the following: some of the artisans do not conduct earthing resistance testing after installation, some do not install earthing systems probably in an effort to cut down cost in order to win a bid from a house owner, and others also use wrongly sized conductors for earthing. These practices raise a concern as to whether these earthing systems are effective or not.

In view of the revelations about the electrical installations of the unlicensed technicians, the purpose of this research is three fold: (1) to assess the effectiveness of the earthing systems carried out by the unlicensed artisans by comparing randomly measured earth resistances with Ghana's Energy Commission domestic earth resistance benchmark, (2) to identify critical factors influencing earth electrode resistance within the municipality, and (3) to design a decision tree model for predicting earth resistance values of given locations. As has already been noted, the artisans do not conduct earth resistance test after installation. The reason can be traced to the fact that the majority of them do not have earth resistance testers (ie, Megger). Hence, there is a strong need for a prediction model to help the artisans know in advance the earth resistance to be achieved in their installations based on their own choices of certain factors before installation.

The rest of the paper is organized as follows: Section 2 presents a brief discussion of the earthing system used in Ghana and factors affecting earthing resistance. Methods and Materials are presented in Section 3. Results and discussions are presented in Section 4. Finally, conclusions and recommendation are presented in Section 5.

2 | EARTHING (GROUNDING)

Earthing or grounding is the same when it comes to electrical or electronic systems. Britain people have “earthing”, and Northern America uses “grounding”.⁹ Earthing is an act of connecting a part of an electrical or electronic system or installation to the general mass of the earth.¹⁰⁻¹² Conductive materials, electrical or electronic circuit, and the general mass of the earth are connected either deliberately by nature or accident through capacitive or inductive coupling.¹³ Research has found that by connecting one point in each electrical circuit to a common point of reference (the earth), the difference of potential between electrical systems could be controlled to make electrical appliance and systems safe.¹³ There are many methods to achieve earthing in low voltage electrical installation system. The British Standard (BS) 7671 lists five types of earthing systems employed in low voltage (LV), namely, TN-S, TN-C-S, TT, TN-C, and IT, where, T = Earth, N = Neutral, C = Combined, S = Separate, and I = isolated.

The TT system is used in Ghana for domestic installation, so the rest of this section will be limited to a discussion on the TT system. Figure 1 shows the TT earthing system. In this system, the neutral of the source of energy is connected

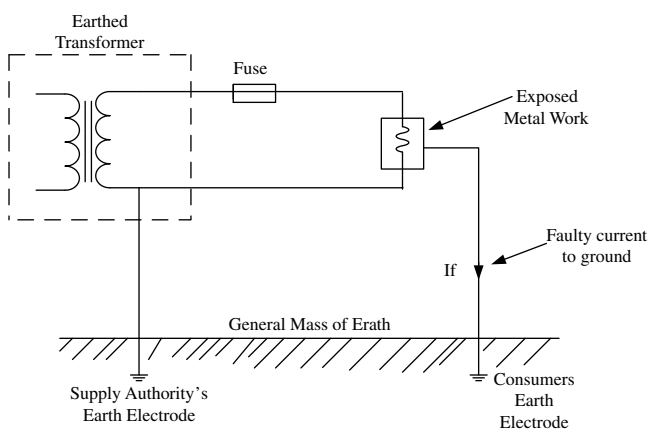


FIGURE 1 TT earthing system

between the supply neutral and the earth at the supply transformer, but the supply authority provides no facility for the consumer's earthing. With TT, the consumers are left to provide the own earthing system, that is, by mounting an appropriate earth electrode local to the installation.¹⁴

2.1 | Earth electrode testing

The values of earth resistance and the earth loop impedance contribute to the effectiveness of an earthing system. These two factors determine how a protective device will react to earth leakage current (earth faults). The higher the impedance, the lesser the effectiveness of the protective device. Earth electrode testing involves two approaches, namely earth system resistance and earth resistivity. Earth resistivity is employed in a new earthing site while system resistance testing is employed in existing installation earthing test.¹⁵

2.1.1 | Soil resistivity

Soil resistivity is the opposition (resistance) offered by soil to the passage of earth leakage (earth fault) current. Soil resistivity determines the earth resistance value. Literature reveals that it varies from soil to soil and is dependent on the physical composition of the soil, dissolved salts, moisture, grain size and distribution, current magnitude and seasonal variation.¹⁶ Study shows that soils with high resistivity possess negative effect on earth electrodes and grids.¹⁷ However, the soil resistivity depends on many factors; below are some factors which determine the soil resistivity to the flow of leakage current:

- i. *Soil condition*: The resistivity of soils is dependent on the soil conditions. Most scorched soils are very poor conductors of electricity. Study shows that every earth electrode performance depends on the soil.¹⁸ A soil with little resistivity is exceptionally corrosive, and dry soils possess high resistivity value, and if the soil resistivity is high, earth resistance of the electrode will also be high.¹⁹
- ii. *Moisture*: The resistivity nature of soil highly depends on the amount of moisture content in the soil. Thus, the soil resistivity can be realized by the amount of water held by the soil and the resistivity of the water itself.²⁰ Electricity conduction in the soil is through the water.¹⁹
- iii. *Dissolved salts*: Distilled (pure) water is a poor conductor of electricity. The resistivity of a soil depends on the resistivity of water, which in turn depends on the nature and amount of salt content in it. A small quantity of salt in water has the potential of reducing soil resistivity by 80%, with common salt being the most effective in improving soil conductivity.^{16,19}
- iv. *Climate condition*: A decrease or increase of moisture content in soil determines the decrease or increase of the soil resistivity.²¹ In the dry weather season resistivity of soils becomes very high, and in the wet or raining seasons, the resistivity is low.
- v. *Physical composition*: Different soil composition gives a different soil resistivity. The resistivity of clay soil lies within the range of 4-150 ohmmeter, whereas for gravel or rocky soils, the same may be well above 1000 Ωm .¹⁹
- vi. *Location of earth pit*: The location of the earth pit also contributes to the resistivity of the soil. In a land with made-up of soil, a sloping landscape or areas which are rocky, hilly or sandy, water runs off in dry weather seasons. In such a situation the attraction of moisture by backfill compound is very poor, causing dryness of soil around the pit. Earthing improvement can be achieved in such area during the dry season through regular watering of pit area is advanced.⁹ Hence, earthing should be sited to a naturally not well-drained site.⁹
- vii. *Effect of grain size and its distribution*: The grain size, its distribution and discreteness of packing are also influential factors since they control how the moisture is clench in the soil.⁹ Effect of weather changes on soil resistivity: Increase or decrease of moisture content in soil determines the increase or decrease of resistivity soil. Thus, resistivity is low in rainy and high in dry weather conditions.¹⁹
- viii. *Effect of the current magnitude*: The fault current flowing from the electrode into the surrounding soil might affect the soil resistivity in the vicinity of the ground electrode. Study reveals that the moisture content and thermal characteristics of the soil determines whether the duration and magnitude and of a given current of a given is capable of causing significant drying, increasing the effect of soil resistivity.¹⁹

- ix. *Area available*: Installation of an isolated earth strip or rod or plate might not achieve the desired earth resistance alone.²² When multiples of earth electrodes are mounted and interconnected, the desired earthing resistance might be achieved. In a way to prevent overlapping of the area influence, the riven depth must be the same as the distance between electrodes. Hence, individual electrodes must be outside the resistance area of the other.²²
- x. *Obstructions*: The surface of most soil appears good; however, there may be obstructions below a few feet like a virgin rock. In that event, resistivity will be affected. Obstructions like concrete structure near the pits will affect resistivity.¹⁹

2.1.2 | Earth system resistance

Earthing systems fall within two groups: simple or complex. The simple systems are made of either a single or small number of electrodes driven into the ground, while a complex system employs multiple earthing points.¹⁵ The resistance value of the earth electrode depends on three key components: (i) the electrode's resistance, which is dependent on the material used for the electrode; (ii) contact resistance between the electrode and the soil it is driven into; (iii) resistance of the surrounding body of soil. Methods for measuring earthing system resistance include direct measurement (dead earth) or 2-pole; fall-of-potential, lazy spike, attached rod technique, and the slope method.

3 | MATERIALS AND METHODS

A detailed description of the step by step approach employed to achieve the objectives of this paper is discussed in this section.

3.1 | Earth electrode resistance test

Site measurement is the most effective way of determining earth impedance even though an initial assessment employing computational methods are useful for the prediction of expected results.²³ Since our study area mainly consisted of existing electrical installations, the Attached Rod Technique (ART) for system resistance testing was adopted (Figure 2). This technique adopted because it measures the loop resistance including all connections and cables.^{6,15} Again, readings provided by this technique is perfect for comparative condition monitoring testing, extraordinarily reliable and conforms to IEEE 81.^{15,24} Finally, ART offers an advantage of clamp-on testing,²⁵ which gave us the ability to carried out the electrode resistance test without disconnecting the ground electrode. ART is a combination of fall-of-potential testing and clamp-on testing.

Specifically, a DET3TC ground tester (Megger) with ICLAMP, equipped with ART capability was considered for all electrode resistance tests reported in this paper. The DET3TC is a 3-terminal ground resistance tester of 100 V, 2000 Ω .

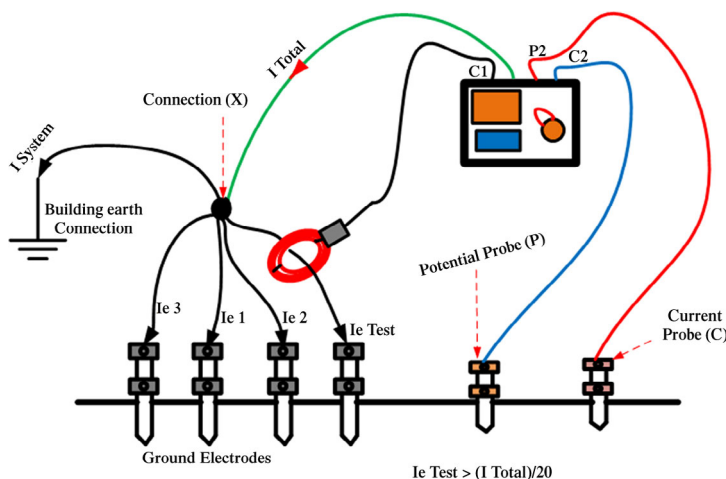


FIGURE 2 Attached rod technique for system resistance testing (adopted from Reference¹⁵)

It is capable of performing both 2 and 3 pole-configuration earth resistance measurements in the range of 0.01Ω to $2 \text{ k}\Omega$ at $\pm 0.5\%$ accuracy and 0.001Ω resolution. With the ICLAMP feature in this instrument, we measured the individual earth electrode resistance of households using a typical fall-of-potential method but without disconnecting electrodes under test. The earthing resistance values reported in this paper are all averages of several values measured in both rainy and dry seasons.

The working principle behind the ART could be summarized in the following steps:

1. Measure the total resistance (R_T) of the system using a typical fall-of potential configuration.
2. Measure the total current (I_{Total}) being injected into the system from (C_1).
3. Measure the current (I_{system}) flowing to building earth electrode.
4. Using Ohm's law as expressed Equation (1) calculate the voltage drop (V_{drop}) from the selected volume of soil to the point of P.
5. Calculate the current via the ground electrode (I_e test) as expressed Equation (2).
6. Determine the ground electrode resistance (R_G) as expressed Equation (3), using the voltage drop and the current through it.

$$V_{\text{drop}} = R_T \times I_{\text{Total}}, \quad (1)$$

$$I_{e\text{test}} = I_{\text{Total}} - I_{\text{system}}, \quad (2)$$

$$R_G = \frac{V_{\text{drop}}}{I_{e\text{test}}}. \quad (3)$$

3.2 | Predictive model

Several machine learning algorithms are available for classification and regression tasks.²⁶ However, the Decision Tree (DT) algorithm was adopted for modeling our dataset based on its simplicity and efficiency with small data size, as reported in the literature.^{26,27} A DT is a form of a flow-chart-like tree structure that uses a branch off method to spell out every distinct likely result of a decision. Every individual node within the tree embodies a test on a precise variable, and each branch is the outcome of that test. DT represents a set of conditions which are organized hierarchically and consecutively applied from root to a terminal node or leaf of the tree.²⁷ An information gain approach was used to decide the appropriate property for each node of a generated tree. The test attributes of each current node were selected based on the attribute that has the maximum information. The algorithm is as follows, let X be a set that includes x number of data samples. With these attributes, several n potentials values corresponding to n different type of C_i can be derived, where $i = 1, 2, 3 \dots n$. The amount of information to classify a given data is shown in Equation (4).

$$I(x_1, x_2, \dots, x_n) = - \sum_i^n p_i \log p_i. \quad (4)$$

In Equation (4), P_i is a probability expressed as $P_i = S_i/|S_j|$, which is any subset of data samples in categories C_i . S_j is the data sample whose attribute A is equal to $a_{ij} \subset X$. By using the property of A , X can be divided into u different number of subsets $\{x_1, x_2, \dots, x_n\} \{x_1, x_2, \dots, x_u\}$. If property A is selected for a test, that is used to make a partition such that X_j is the sample set C_i in the subset S_i , then the information entropy and the gain (A) can be obtained using Equation (5) and (6), respectively. The decision tree algorithm in this study was implemented using Weka.

$$E(A) = \sum_{i=1}^n \frac{x_i}{n} I(x_1, x_2, \dots, x_n), \quad (5)$$

$$\text{Gain}(A) = I(x_1, x_2, \dots, x_n) - E(A). \quad (6)$$

Figure 3 shows a dataflow diagram of the predictive model. The dataset from the survey consisted of location-of-earth-pit, number-earth-electrode-used, earth-electrode-size, soil-type and earthing-conductor-size. We

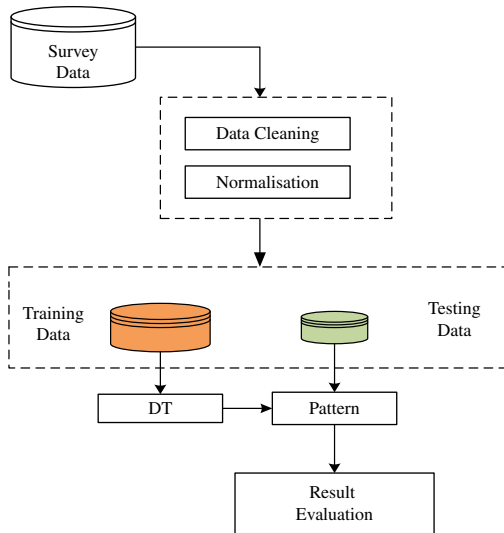


FIGURE 3 Data flow diagram of the predictive model

preprocessed the dataset to remove noise, missing values were replaced with average values and then normalized in a range of [0,1] using Equation (7) for better prediction accuracy. The preprocessed dataset was partitioned into training data (85%) and 15% for testing as showing in Figure 3.

$$x' = \frac{x - x_{\min}}{x_{\max} - x_{\min}}, \quad (7)$$

where x' , the new value obtained after normalization; x , the value to be normalized, x_{\min} and x_{\max} are the minimum and maximum value of the dataset.

The root mean square error (RMSE) and mean absolute percentage error (MAPE) as expressed in Equations (8) and (9)²⁶ were employed to evaluate the performance characteristics of the decision tree as follows:

$$\text{RMSE} = \sqrt{\frac{1}{n} \left(\sum_{i=1}^n (m_i - p_i) \right)}, \quad (8)$$

$$\text{MAPE} = \frac{1}{n} \sum_{i=1}^n \left| \frac{m_i - p_i}{m_i} \right|, \quad (9)$$

where m_i is the measured value, p_i is the predicted value, and n is the number of the predictions carried out.

4 | RESULTS AND DISCUSSIONS

This section presents the results and discussion of the current study.

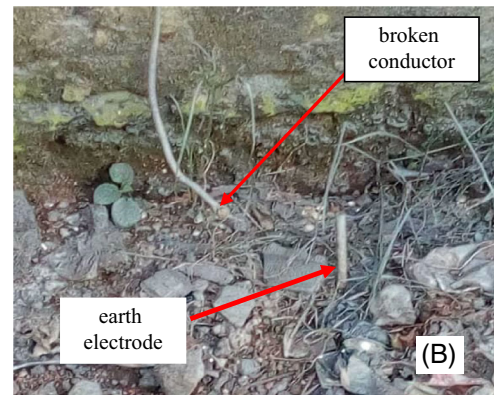
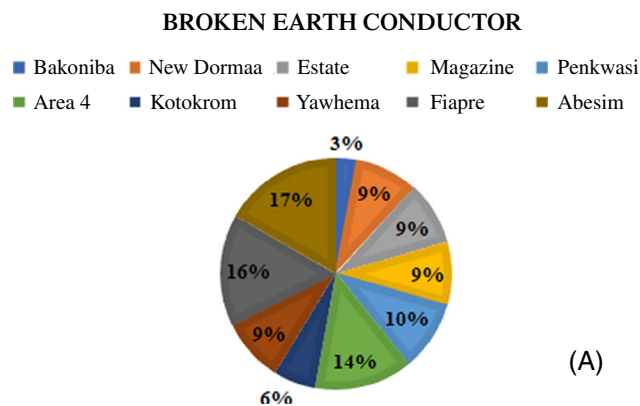
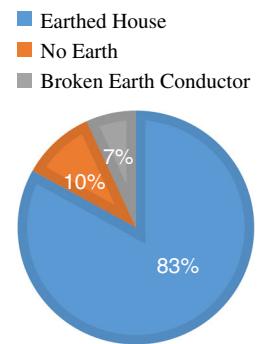
4.1 | Earthing system in Sunyani municipal

Ten communities within the Sunyani municipality were randomly select, and 1004 houses were conveniently sampled from the 10 selected communities. The consent of each household was sought, and the purpose of the study was explained to them in their local dialect. Survey data was collected from January 2016 to April 2018. Table 1 shows the distribution among the selected communities. The outcome of the study revealed that the earthing system used was TT Earthing System, and every consumer of electrical energy is required to produce their earthing arrangement in their residence.

Figure 4 shows the outcome of the survey based on the number of houses that had earthing, no earthing, and broken earth conductor (earthing lead). Out of the 1004 houses that were surveyed within the Sunyani municipality 834 had

TABLE 1 Survey distribution

S/N	Community	House surveyed	Percentage
1	Bakoniba	64	6%
2	Magazine	45	4%
3	Penkwasi	64	6%
4	Area 4	69	7%
5	New Dormaa	137	14%
6	Kotokrom	120	12%
7	Yawhema	126	13%
8	Abesim	183	18%
9	Estate	59	6%
10	Fiapre	137	14%
Total		1004	100%

FIGURE 4 Earthed, no earth and broken earth**FIGURE 5** (A) Results of broken earthing conductor. (B) An image of observed broken conductor

their houses connected to the ground (earthed) making 83%. One hundred and one houses had no-earthing, representing 10%, while 69 had their earthing conductor broken (thus no continuity between earthing conductor and earth electrode), making 7%.

Out of the 69 houses that had broken earthing conductor, Abesim tops the list with 17% representing 12 houses with no earth whiles Fiapre had 16% representing to 11 houses. Figure 5A presents the breakdown of observed broken earthing conductor with the municipality. Figure 5B shows a sample of the broken earth conductor observed.

One hundred and one buildings were noted not to have earthing. Abesim had 19 houses with no earth as the highest, Yawhema at the second position with 17 buildings with no earthing and Penkwasi at the bottom with two houses with no earth. It is revealed that buildings in New Dormaa are highly earthed, and this can be attributed to the fact that the area is a new settlement.

Earthing conductor size (mm ²)	No. of houses
1.5	323
2.5	216
4	71
6	47
10	49
12	51
16	77

TABLE 2 Sizes of earthing conductor

Earthing conductor resistance (Ω)	No. of houses	Percentage (%)
0.1	24	2.88%
0.2-0.5	68	8.15%
0.6-1.0	84	10.07%
1.1-2.0	176	21.10%
2.1-3.0	148	17.75%
3.1-4.0	128	15.35%
4.1-5.0	89	10.67%
5.1-6.0	55	6.59%
6.1-7.0	16	1.92%
7.1-8.0	21	2.52%
8.1-9.0	11	1.32%
9.1-10.0	14	1.68%

TABLE 3 Earthing conductor resistance frequency table

4.2 | Earthing conductor size

Table 2 shows the various sizes of cables employed as earthing conductor in the Sunyani municipality. Out of the 834 houses that had earthing system in place 38.73% use 1.5 mm² cable as earthing conductor, 25.90% employ 2.5 mm², 8.51% uses 4 mm², 5.64% use 6 mm², 5.88% use 10 mm², 6.12% use 12 mm² while only 9.23% use the prescribed earthing conductor by the Ministry of Energy of Ghana (thus 16 mm²). The study found that the most common conductor size employed by electrical artisans and electricians as an earthing conductor is 1.5 mm² cable, as shown in Table 2.

4.3 | Earthing conductor resistance test

Table 3 gives the frequency distribution of the earthing conductor resistance obtained from the 834 houses that had an earthing system. The study found that only 2.88% of the 834 houses that had earth has an earthing conductor resistance value within the acceptable range value by the Energy Commission of Ghana, as seen in Table 3. One can deduce from Table 3 that the general earthing conductor resistance within domestic installations in the Sunyani municipality is above the accepted range.

To ascertain and confirm that the earthing resistance of an electrical installation partially depends on the conductor size used for earthing, 50 random samples of the earthing conductor resistance measured were taken for each conductor size and the same soil type, and the average earthing resistance for each conductor was calculated.

Table 4 shows the average resistance obtained for each conductor size. From Table 4, one can say that the bigger the cross-sectional area of the earthing conductor, the lesser the resistance offered to the flow of earth fault. Some of the earthing terminations were having some issues, such as improper termination of earthing lead to earth electrode (Figure 6A).

TABLE 4 Average-earthing resistance based on earthing conductor size

Earth conductor size (mm ²)	Average earthing conductor resistance (Ω)
1.5	3.19
2.5	3.04
4	2.99
6	2.51
10	2.13
12	1.02
16	0.06

FIGURE 6 (A) Improper electrode termination. (B) Exposed buried earth electrode**TABLE 5** Earth electrode test result

Earth electrode resistance test	No. of houses	Percentage %
0.0-5.0	5	0.60%
5.5-10	23	2.76%
10.5-15	124	14.87%
15.5-20	150	17.99%
20.5-30	532	63.79%

Again, it was observed that some electrodes were not correctly buried (Figure 6B), and these can contribute to the average earthing resistance values.

4.4 | Earth electrode test distribution

Table 5 presents the distribution obtained from the earth electrode test conducted on the 834 buildings that had the earthing system in place. From Table 5, 28 buildings earth electrode resistances were within 0.0 to 10 Ω representing 3.36% of the total houses that had an earthing system. While 96.64% had their earth electrode resistance far above the acceptable benchmark value by the Energy Commission of Ghana. Furthermore, we observed that the earth resistances measured in homes that had their earth electrode buried close to a septic tank, or moist areas were moderate (within 0.3-0.6 Ω). This observation can be attributed to the amount of moisture in the soil due to the drainage system around these locations. Again, homes that had more than one earth electrode buried also experienced low earthing resistance. The reason for the low resistance can be attributed to the parallel paths created by the multiple electrodes buried. Figure 7 shows an observed earth electrode buried in a water log environment.



FIGURE 7 An electrode buried in a water log environment

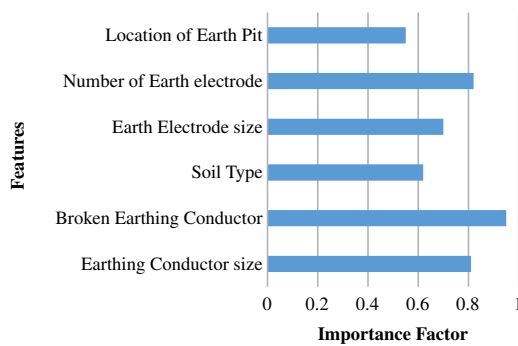


FIGURE 8 Feature importance

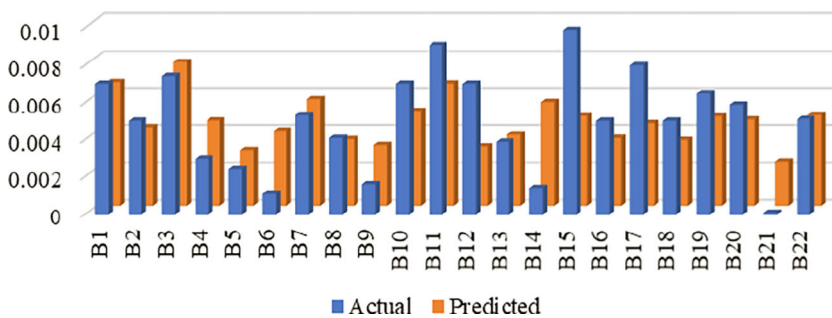


FIGURE 9 Plot of actual and predicted values

4.5 | Earthing resistance prediction

Feature selection offers useful information on the relative importance or relevance of features for any given problem.^{22,23} At this section, the aim was to predict the earthing resistance using the measured data from the survey. Figure 8 shows the feature ranking of the input features by the DT algorithm. The study revealed that broken earth conductor and number of earth electrode buried were the most significant feature in determining earthing resistance of an installation. The outcome confirms the high earthing resistance of building with the broken earthing conductor.

Figure 9 shows a plot of actual values and predicted values. The outcome of this study reveals that the top four (4) features namely: broken earthing conductor, earthing conductor size, number of earth electrode used and earth electrode size can effectively predict the earthing resistance of installation with an accuracy of 98%. The RMSE (0.04) and MAPE (0.01) reveal a close gap between measured values from the survey and predicted value by the DT models. This outcome reveals that the decision tree model can use to effectively predict earthing resistance from other areas based on the selected feature.

5 | CONCLUSIONS AND RECOMMENDATIONS

In this study, we attempted to examine the effectiveness of earthing in domestic installation within the Sunyani Municipality. As a result, 1004 households earthing resistance were measured using Megger. The measured features from the survey were then used as input features to a decision tree model to identify the factors that profoundly affect the earthing resistance in the Municipality and also predict earthing resistance of future household based on measure features. The study revealed that soil type, earth rod size, earthing conductor size, number of electrodes used and the location of earth pit were the factors that determine the earthing resistance in the Sunyani Municipality. We summaries the outcomes of the study as follows:

- The maximum, minimum and average earthing conductor resistance was 9.3, 0.1, and 2.84 Ω respectively. A high percentage (88.97%) of the earthing system in residential buildings in the Sunyani municipality have their earthing conductor resistance value above the acceptable value (0-0.1 Ω) by the energy commission of Ghana. This outcome implies that the risk of occupant getting electrocuted in the event of earth fault is very high. Twenty-eight homes earth electrode resistance fell within 0.0 to 10 Ω making 3.36% while 96.64% had their earth electrode resistance above the acceptable value by the Energy Commission of Ghana. Hence, this research can conclude that the general earthing effectiveness within the Sunyani municipality is above the accepted value.
- Most electrical artisans and electricians do not perform the required earthing test as required by the supply authority and energy commission of Ghana, and even if they do, the actual values measured are not recorded in the energy meter application forms provided by energy commission of Ghana and the supply authority.
- Most electricians do not use the stated conductor size for earthing conductor, as seen in Table 2. Thus 38.73% (323 out of 834) of the earthing conductor is 1.5 mm².
- A high percentage of artisans' doe did not construct an earthing pit for earth electrodes. On the other hand, a building that has earthing pit do cover them with concrete, which reduces the amount of moisture content in the immediate soil around the earth electrode.

The recommendations of this research could be summarized as follows:

- Since poor earthing does not only contribute to unnecessary downtime but also dangerous and increases in the risk of equipment failure and electric shock to uses of electricity. The Energy Commission and the supply authorities in addition to making the rules should carry periodic inspection of an existing earth electrode of various households to enforce their rules and regulations.
- Earthing pits should be big and deep (at least $1.5 \times 1.5 \times 3.0$ m³.) and electrodes should be buried deep (at least 4 ft) to reduce earthing resistance, and earthing conductor termination to earth electrode should be done well. As the ground rod is driven deeper into the earth, its resistance is significantly reduced.
- Again, to improve the safety, we recommend other earthing schemes, like TN-C-S or TN-S in conjunction with earth electrodes at the customer installations as an alternative strategy for effective earthing
- Furthermore, Residual Current Devices should be installed in domestic installation to protect people against indirect contact.

For Treatments for minimizing Earth resistance, this research recommends the following acceptable conventional methods;

- Remove Oxidation on earth electrode joints, and earthing conductor joints to earth electrode should be tightened.
- Regularly pour enough water in the earth electrode area.
- The bigger size of Earth Electrode with an average height of (4 ft) or more must be used for earthing.
- Artisans and Electrician should employ multiple electrodes (two or more) burring within domestic and commercial installation where the soil resistivity is poor
- Earth pit construction must concentrate on depth and width-breadth of the pit, and ground rods should be placed as deep as possible into the earth as soil and water are usually more stable at deeper levels.

The overall earthing resistance of the Sunyani municipal from the survey proofs fatal. Given this, future research should look at how the earthing resistance within the municipality can be improved by using local materials such as charcoal, sawdust, cow dropping, among others.

ACKNOWLEDGEMENTS

The authors appreciate God's guidance and protection through this survey and to the staffs and faculty members of STU, a huge thank you for all your support.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTION

Isaac Nti, Methodology-Equal, Visualization-Equal, Writing-review & editing-Equal; Albert Appiah, Methodology-Equal, Writing-original draft-Equal, Writing-review & editing-Equal; Owusu Nyarko-Boateng, Data curation, Validation and Writing-original draft.

ETHICS STATEMENT

The authors of this paper declare that all protocols and procedures employed in this research conform to the Energy Commission of Ghana standards, International Standard IEC 60364 and IEEE 81 standards.

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How to cite this article: Nti IK, Appiah AY, Nyarko-Boateng O. Assessment and prediction of earthing resistance in domestic installation. *Engineering Reports*. 2020;e12090. <https://doi.org/10.1002/eng2.12090>