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A novel approach for grounding resistance estimation

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ABSTRACT

Grounding is crucial to achieving equipment and personnel protection. This paper presents input-output pair-based modeling using the response surface method and artificial neural network to predict earth resistance for novel factors associated with grounding. The effect of various types of cone-shaped earth electrodes, charcoal size, and industrial waste metal fibers on earth resistance is investigated for the first time. The experimental trials are carried out in a scaled down manner. Artificial neural network and response surface method are used as investigatory tool for parametric variation. Artificial neural network model predicts earth resistance with more accuracy as compared to response surface method. These methods are found to be very effective in prediction of earth resistance of grounding system which is complex in nature.

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1. INTRODUCTION

Grounding is used to keep people and instruments safe. Low earth resistance is required for good grounding. The grounding electrode and the soil conditions around it are critical. Natural and man-made changes have had an impact on the factors influencing grounding resistance. Seasonal patterns are shifting, and their impact on grounding is palpable. The population is growing, and so is the rate of concretization. Because of changes in soil, grounding methodology has changed dramatically. Automation necessitates a lower grounding resistance. As a result of these developments, the grounding approach, and many components of grounding, from construction to commissioning, must be reexamined. Different strategies for achieving lower earth resistance are the subject of a research. The primary function of grounding is to provide path of low electrical resistance. Ground electrode and soil conditions around ground electrode are the major contributors to lower grounding resistance which have been extensively studied [1].

Various subfactors of these to reduce grounding resistance have been tried by many researchers. Electrode's parameters like material, depth in soil, shape and parallel connection have been altered to lower grounding resistance [2]–[7]. Contact between soil and electrode structure aids in lowering grounding resistance. Since a long time, various methods have been used to alter soil resistivity [8]–[11]. As soil improvers, a variety of materials have been introduced. These materials are classified into two types: organic and inorganic. An organic enhancement material is typically made of natural materials, whereas a chemical product is made of inorganic materials. Natural materials have seen an increase in demand in recent past. This is due to the abundance of raw materials which are inexpensive. In the early 1980s, Jones [12] proposed bentonite rods as a soil improver. In his experiment, Bentonite rods were field tested against driven rods at three different soil texture sites. The findings revealed a significant reduction in grounding resistance of up to 36% that remained consistent throughout the year. Kostic *et al.* [13] investigated the electrical properties of grounding loops using bentonite suspension, bentonite powder, and mud waste drilling as improving agents with limited success. Eduful *et al.* [14] introduced the various natural materials, such as coconut peat, paddy dust, and palm kernel oil cake, and the results were compared to bentonite. Experiment results show that these compounds have a remarkable ability to preserve soil moisture and significantly reduce grounding resistance without loss, even after rainfall. Jasni *et al.* [15] tested bentonite, cocoa coir peat, planted soil, and paddy dust. The planting-clay soil is identified as the most effective enhancement compound in comparison to the others because it provides the lowest grounding resistance and, in general, the greatest degree of reductions during the project period. Another method for reducing grounding resistance, using Dead Sea water, was proposed by El-Tous *et al.* [16]. However, due to the porosity of the land and the size of the plant, the Dead Sea water must be replenished every second year. Nyuykonge *et al.* [17] developed a method for treating soil that involves replacing soil near electrodes with biochar rather than chemicals. As compared to the situation without soil treatment, the findings of the trials reveal that biochar generated from rice straw greatly reduces grounding resistance. Industry waste products have a harmful impact on the environment. According to numerous reports, industrial waste is the primary source of pollution. It could be beneficial if the waste product is recycled for a good cause. Researchers have lately begun investigating if the waste product may be used in a grounding system. In the reduction of grounding resistance, several types of industrial waste products have been identified [18]. Fly ash is produced when coal is burned in a power station. Fly ash disposal is expensive, polluting, and has negative environmental consequences. The characteristics and performance of fly ash material as grounding system enhancement material have been studied by Chen *et al.* [19].

Reduction of grounding resistance through modeling approach is hardly seen in available literature. Grounding is complex system also its laborious, time consuming and costly to conduct trials for investigation so it qualifies for statistical modeling approach. Statistical methods are suitable for parametric variation studies in many fields [20]–[25]. The factors and response relationship can be established either by statistics or the machine learning. Artificial neural networks (ANN) mimic biological neural networks. ANN have gained considerable acceptance due to their features such as the resolution of complex problems, the identification and ability to generalize and learn [26], [27]. These techniques can be used for analysis and improvement of grounding [28]. From literature survey, it is found that some subfactors are not investigated for reduction of ground resistance. It is also found that statistical methods are hardly used in grounding analysis. There is a need to investigate some subfactors of grounding which are ignored so far. This paper presents investigation of subfactors affecting grounding resistance using response surface methodand ANN approach. Novelty of presented work is in estimation of grounding resistance with least explored, economical parameters using statistical method modelling the following is the outline of the paper. Section 2 of this paper presents basic information for use of Response surface method and ANN for grounding system. The investigations of effects of some new subfactors are carried using statistical method for the first time for research in the field of grounding. Section 3 describes experimentations and results pertaining to the implemented modeling methods. The last section details the conclusion of the research work presented.

2. RESEARCH METHOD

2.1. Factors influencing ground resistance

Major objective in designing grounding system is reducing grounding resistance value in best possible way. Prime factors affecting grounding resistance along with their subfactors are shown in Figure 1. The grounding resistance is reduced by varying depth, diameter, and material of grounding electrode. Deep driven electrodes give less grounding resistance. As the diameter of grounding electrode increases, contact area with soil increases which lowers grounding resistance. The most preferred option between these two is deep driven electrode from practical concerns. Composition, moisture, and temperature of soil affect the grounding resistance value. More salts in soil around electrode helps in easy passage of current. Grounding resistance is less in presence of moisture. Increase in temperature results in rise in soil resistance. Backfills can be natural, chemical materials even waste products are used as backfill material. For modeling all factors cannot be considered simultaneously. Most significant factors or factors requiring desired analysis are considered in modeling. Three factors cone shaped electrode, charcoal size and metal scrap addition are considered as input factors in modeling presented in this paper.

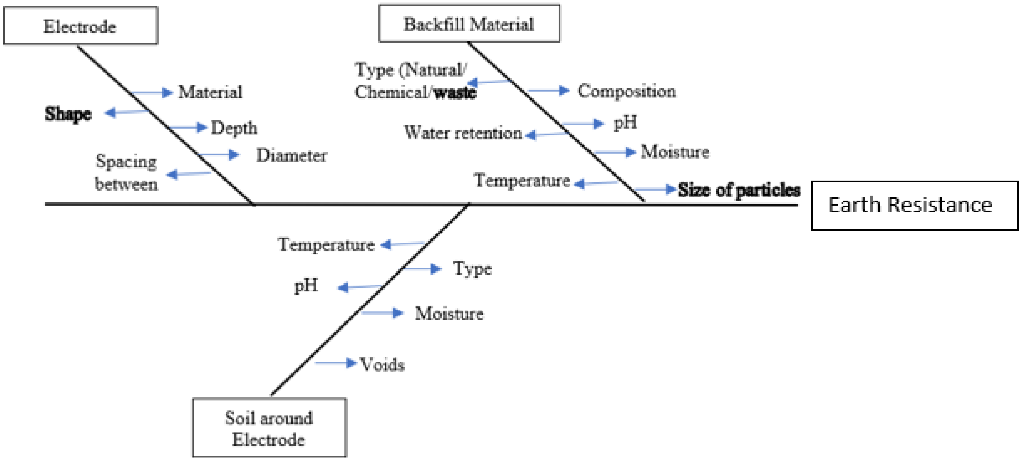

Figure 1. Factors affecting grounding resistance

Plenty of factors affecting grounding resistance are studied and reported. This study focuses novel parameters affecting grounding resistance yet giving cost effective option. A hollow cone-shaped electrode is being considered because of the space constraints. The cone surface area is greater than that of the pipe in given grounding pit volume. Due to the less well-documented nature of the change in the size of charcoal in the literature, this parameter is worth for further research.

Soil enhancements can be natural or chemical in nature. Wastes in the form of steel scraps are produced by lathe machines during the process of finishing various machine parts in each lathe industry are used as backfill material. Similar materials for electrode and scrap are chosen to avoid corrosion issues. A low-cost soil improver is attempted by combining metal scrap with charcoal and salt. Trials are carried out to study the extent of the effects of the variation in aforementioned factors, and statistical methodology.i.e., response surface method is used to develop a model for grounding followed by ANN approach.

Major objective in designing grounding system is not only to achieve lowest possible grounding resistance value but it should be economical and feasible. Experimentation to study the effect of parameters requires multiple trials which are costly, time consuming. Hence, the scale down approach is used during all trials. Prior multiple full-scale trials and scaled down trials are carried out. Scale down factor of seven is obtained to get grounding resistance value for standard pit dimensions. The different pits had different composition as per need of trials. The resistance is measured on different days for every pit in particular time slot and mean value is taken.

For scaled down trials, pit dimension of one cubic foot is considered. Cone electrode is placed, and then pit is filled with charcoal, salt, metal scrap as per requirement of trials as shown in Figure 2. The depth of cone below ground is shown as ‘L’,while ‘D’ isdiameter of hollow coneshaped electrode. Grounding resistance is measured using three-point method in all trials. Details of experimentation and results of modeling methods are as Figure 3.

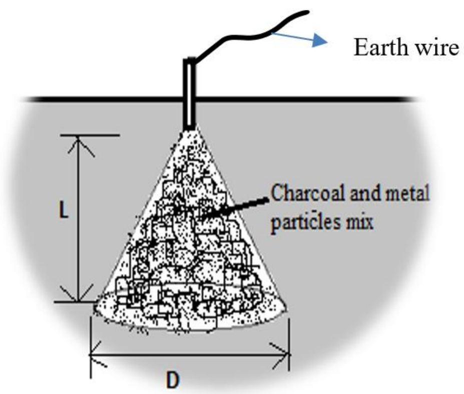

Figure 2. Experimental pits for trials with mixture charcoal, salt, and metal particles in as well as around cone shaped electrode

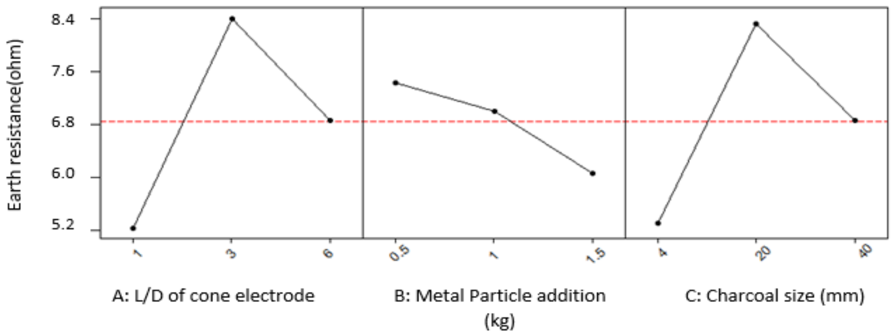

Figure 3. The effects of cone electrode's L/D ratio, metal particle addition and charcoal size on grounding resistance

2.2. Methods used for modeling of grounding

2.2.1. Response surface method

Statistical methods are helpful in systematically finding the response due to different input factors by saving resources [29], [30]. Grounding is expensive, time-consuming, laborious, and therefore its good candidacy for statistical modeling. The aim of this study is to examine in the best way possible the impacts of process inputs on the output responses, the individual and interactive effects of different inputs. This leads to cost-effective solutions focused more on the main parameters and their interactions. Response surface method (RSM) is used to get systematic design trials for experimentation. The input output data from these trials are then fed to ANN to predict output.

2.2.2. Artificial neural network

Nonlinear nature of factors' impact on output can be well predicted using ANN [31]. This method can be very effectively used to predict grounding resistance by feeding necessary input, output to system. There are many artificial intelligence techniques available, but they need to be further developed and adapted to grounding design. Supervised learning maps input-output pairs, neural network method is a type of machine learning. A neural network is a network of equations that takes in an input and returns an output or a set of outputs [32]. Neural networks are composed of various components like an input layer, hidden layers, an output layer, and nodes as shown in Figure 4. Each node is composed of a linear function and an activation function, which ultimately determines which nodes in the following layer get activated. Sigmoid function is used in ANN for regularization. New statistical modeling method and artificial intelligence techniques offer fantastic opportunities for our grounding system knowledge.

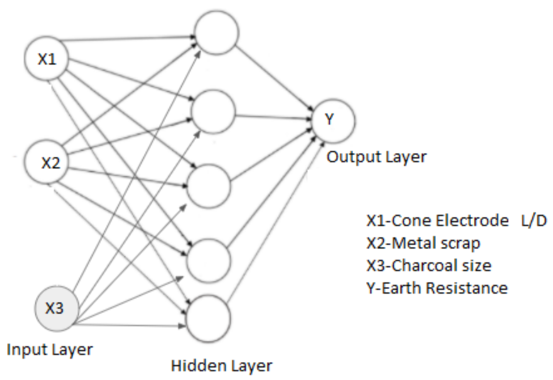

Figure 4. ANN model for grounding resistance prediction

3. RESULTS AND DISCUSSION

After brief discussion of modeling method used for prediction of grounding resistance, this section deals with results related to said modeling methods. When designing an earthing system, the primary goal is to achieve the lowest earth resistance possible while remaining economically and technically feasible. Design considerations include electrode shape, metal particle addition, and charcoal particle size.

3.1. Response surface method

The effect of parameters on grounding resistance is studied using experimental trials designed using RSM. It is useful for building quadratic relationship between output response and input variables. User can decide target earth resistance value and by using parameter variation in RSM model can achieve targeted earth resistance value. The experimental design procedure explained in flowchart Figure 5.

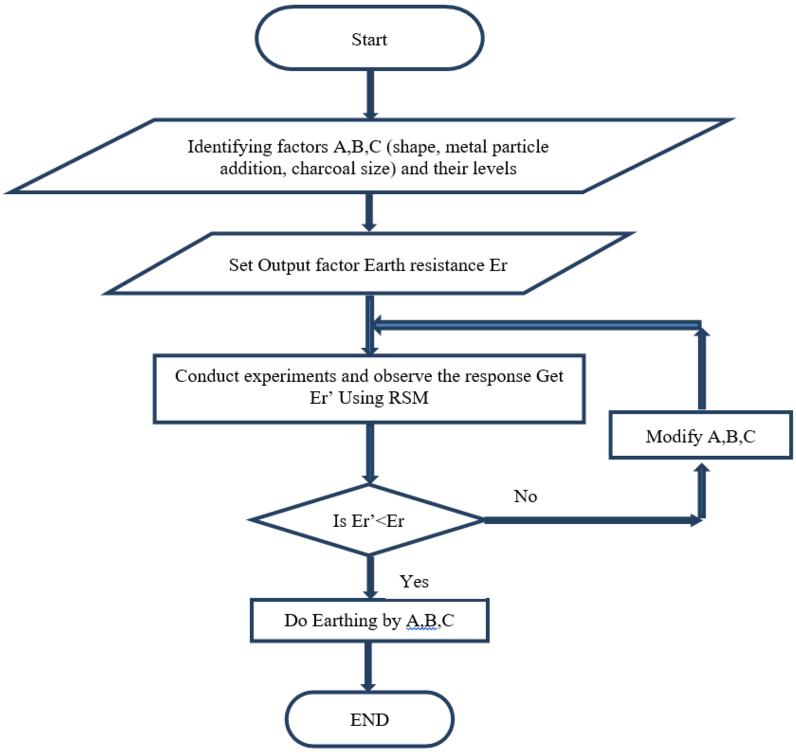

Figure 5. Flowchart for RSM process

Generalized second order response model developed using RSM is represented as (1):

$$Y = b_0 + b_1X_1 + b_2X_2 + \cdots + b_{11}{X_1}^2 + b_{22}{X_2}^2 + b_{12}X_1X_2 + \cdots b_{n-1,n}X_{n-1}X_n \quad (1)$$

where, Y is output response and Xi are input factors. Least-square method is used to compute the regression coefficients bi. Statistical analysis is used to obtain significance of factors and their interactions. For RSM, the required experimental and coded levels of input factors are given in Table 1. Three input factors in the experiments of RSM design requires 20 trials as shown in Table 2.

Table 1. Input factors and their coded levels for RSM trials

Input factors	Coded factors	Levels of coded factors				
		Low	Low-Medium	Medium	Medium High	High
		−1.6817	−1	0	+1	+1.6817
L/D ratio	A	0.5	1	3	6	9
Metal addition (kg)	B	0.25	0.5	1	1.5	2
Charcoal size (mm)	C	1	4	20	40	60

The RSM technique is used to investigate individual and interaction effect on grounding resistance for three input factors. Experiments are carried out s per Table 2. Minitab software is used to obtain RSM model is shown in (2).

$$R = 8.04 + 0.47A - 0.63B + 0.93C - 0.98A^2 + 0.21B^2 - 0.8C^2 - 0.18AB - 0.68AC - 0.17BC \quad (2)$$

Table 2. RSM trials for investigation of effect of selected factors (coded values) on grounding resistance

Run	L/D (A)	Metal addition (B)	Charcoal size (C)	Grounding resistance (ohm) (R)
1	0.00000	0.00000	1.68179	7.00
2	0.00000	0.00000	0.00000	8.00
3	1.00000	-1.00000	1.00000	8.60
4	1.00000	1.00000	-1.00000	6.50
5	0.00000	0.00000	0.00000	8.00
6	0.00000	1.68179	0.00000	7.20
7	0.00000	0.00000	0.00000	8.10
8	1.68179	0.00000	0.00000	4.50
9	0.00000	0.00000	0.00000	8.10
10	-1.00000	1.00000	-1.00000	3.00
11	0.00000	0.00000	-1.68179	5.50
12	1.00000	1.00000	1.00000	7.50
13	0.00000	0.00000	0.00000	8.00
14	-1.00000	1.00000	1.00000	6.40
15	-1.00000	-1.00000	1.00000	7.10
16	0.00000	-1.68179	0.00000	11.00
17	0.00000	0.00000	0.00000	8.00
18	1.00000	-1.00000	-1.00000	7.25
19	-1.00000	-1.00000	-1.00000	2.70
20	-1.68179	0.00000	0.00000	7.00

Factor which is showing more significant effect is particle size of charcoal used in grounding pit. It is followed by length to diameter ratio of cone. Metal particle addition shows the least effect amongst all. The contributions of A, B and C factors are 45%, 31% and 48% respectively in grounding resistance value. If length to diameter ratio is less, then charge transfer is more in the soil. The backfill material is encased by it and remains in contact with inner and outer surface which aids in lowering resistance. In case of deep driven rod, grounding resistance value depends on type of soil at deeper level. Cone shaped electrodes can do away the need of deep driven grounding electrodes. Thus, it is also felt that cone shaped electrodes could be better at many places with rocky soil at depth. The particle size of charcoal used as backfill material is a new factor investigated in the presented work. Fine powder of charcoal facilitates conduction process due to increase in surface area available for charge transfer, thereby reducing grounding resistance value. Large size charcoal particles result in presence of fewer air pockets in soil which in turn reduces grounding resistance. Over a long period, the large coal may break down due to the pressure of soil and other materials. Hence, for practical purposes small size of charcoal below four millimeters is recommended which is one of the research contributions of presented work. Metal particle addition lowers grounding resistance. The material used and soil conditions are important. The material of metal particles must be the same as the material of the parent electrode to reduce corrosion effect. Scrap of materials like SS304, SS316 can be used as they have greater resistance to chemical degradation. The interaction between factors and non-linear relationship is also presented by using the RSM model. It is found that the length to diameter ratio has a nonlinear effect on grounding resistance. The particle size of charcoal also affects grounding resistance. The length to diameter ratio of the cone electrode and particle size of charcoal used as backfill material has an interaction effect. The interaction effect of other factors is very less.

3.2. Artificial neural network

For the grounding resistance prediction, a network with five sigmoid hidden neurons and one linear output neuron was used. The learning was done using the Levenberg-Marquardt backpropagation algorithm. This algorithm tries to minimize the sum-of-square error function. Neural networks learn several weights which map output inputs best are given in Table 3. The designed trials are used as the training set to build the model. Data from Table 2 is used to train a model using Python. ANN model gives output as given in (3).

$$R = 7 + 0.3\,A - 0.4B + 0.6\,C \quad (3)$$

Table 3. The weight values of each parameter of the ANN

Sr No.	Input parameters	Hidden layer values				
		N1	N2	N3	N4	N5
1	L/D (A)	0.6309	0.4498	-1.222	-1.21	-0.233
2	Metal addition (B)	0.8209	-0.064	-1.626	0.4252	0.1759
3	Charcoal size (C)	-1.533	-0.286	-0.13	0.4494	0.7565

The model equation reveals that charcoal parameter size is a prominent factor affecting grounding resistance. The contributions of X1, X2 and X3 factors are 23%, 31% and 45% respectively in grounding resistance value. The error values of both models are given in Table 4.

Table 4. Error values with different models

Model	% Mean absolute error	% Mean squared error
RSM	1.67	5.82
ANN	0.9	1.2

From Table 4, it is evident that ANN gives better prediction with less error. The robustness and accuracy of the model obtained by modeling are proven by experimental validation. Some sets of values of input factors in the experimental range are randomly selected and experimentation is carried out. Table 5 presents the experimental details of the actual values of input factors, the predicted values obtained models along with experimental value of grounding resistance for randomly selected trials.

Table 5. Comparison of experimental and model results

Sr No.	L/D (A)	Metal addition Kg (B)	The particle size of charcoal mm (C)	Grounding resistance value in ohm		
				Experimental	RSM model	ANN model
1	0.75	0.375	2.5	5.5	2.34	6.28
2	1.5	0.75	12	6.7	7.00	6.71
3	4.5	1.25	30	7.3	7.77	7.22
4	7.5	1.75	50	7.0	4.40	7.65

Difference between the model predicted values and experimental values of grounding resistance found to be less than 5% in the ANN model whereas in the RSM model it was around 15%. RSM gives information of interaction effect and presence of non-linearity. RSM gives better prediction accuracy in range of -1 to1 of coded values and hence user should select parameters in this range. ANN is better in prediction by considering the underlying nonlinearity of inputs.

4. CONCLUSION

The presented work of novel factors affecting grounding resistance is carried out by the statistical design of experiment methods followed by the ANN method. This innovative approach for prediction of grounding resistance is very effective. RSM and ANN methods are used to the find effect of three new factors of grounding. Factors investigated are the length to diameter ratio of the cone-shaped electrode, metal scrap addition, and particle size of charcoal used as backfill material. They are hardly investigated so far, and it is found that they influence the grounding resistance value. Both these methods are directing towards particle size of charcoal as the most significant factor amongst considered factors. Apart from this both models are projecting equal contribution of metal particle addition factor. This is main finding of presented research work. These factors are investigated in the scale-down grounding pit which is also an innovation in the presented work. The interaction effect between the cone-shaped electrode and charcoal size is found to be dominant due to the better significance of contact between the two. New grounding parameters and innovative approach for grounding resistance estimation is novelty of presented work. Presented RSM, ANN techniques can be used to predict grounding resistance of given site. Proposed methods are responsive to other forms of ground electrodes with necessary modifications pertaining to shape of electrode. Results obtained are closely matching with experimental values. ANN is better than RSM for the prediction of grounding resistance. The study concludes that RSM is a good mathematical tool for analyzing parameter variations and response in an optimized way for grounding system while ANN is better in the prediction of grounding resistance in multivariate and nonlinear process grounding. RSM model error is 15% while in the ANN model it is around 5%.

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