



# Improving the Grounding System in 33/11 kV Distribution Substations

Hamsa Fawaz Thanoon<sup>1</sup>, Layth F. Kamal<sup>2</sup> and Firas M. F. Flaih<sup>2</sup>

<sup>1</sup>College of Electronics Engineering, University of Nineveh, Mosul, Iraq

<sup>2</sup>State Company of the North Distribution Electricity, Ministry of Electricity, Baghdad, Iraq

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**Abstract:** The grounding is the connection of the metal structures of machines with electrical equipment in order to remove the electrical charge from the earth by the grounding through locked connection and to prevent possible damaging of the equipment and the loss of the operator's life. Thus, any construction will have a risk produced by a fault current or lightning unless has a suitable grounding system. According to the international standards, the agreed grounding resistance should be 1  $\Omega$  or lower. The challenge is to get the standard value of grounding resistance under various environmental conditions. Therefore, to manage troubled environments that suffer from high resistivity soil, bentonite substance has been proposed to use for electrical grounding applications in distribution networks to get the lowest value of grounding resistance. Ground network of eight 33/11 kV substations with its conductors are designed then part of the electrode holes are filled by bentonite. The designed T-shape was used in the implementation of the selected substations according to the standard reference IEEE Std. 80-2000/2013. A T-shape is chosen for its economical purpose based on the conductor length utilized compared to other models (rectangular, square and L-shapes). The ground network resistance for each substation was examined and measured at various anchorage points for one month. The resistors' performance was studied utilizing an earth tester device, and the simulations software was ETAP 16.0.0. Our suggestion shows promising results and a considerable decrease of about 75% for the earthing resistance which contains a certain percentage of the substance. In addition, an acceptable error ratio resulted between the simulation and measured values of earth resistance which opening new prospects for using ETAP in distribution utilities.

**Keywords:** Distribution networks, Bentonite material, Electrical transient analysis program

## 1. INTRODUCTION

Grounding aims to protect a person against the dangers of electric current in the event of electrical equipment or metal structures, which can carry electrical charges resulting from a defect in such appliances. Contact between the electric current with the metal structure of those appliances occurs in one of the components as a result of losing grounding. There are lots of risks generated by electricity usage, sometimes due to environmental circumstances or to the sudden and large changes in electrical systems voltage rises. Different variables such as faults occurring by touching circuit connectors with high-voltage connectors or thunderstorms generate a high voltage. The performance of earth protection systems, power, and communications systems is critical to the general efficiency of lightning protection. The earth protection system aims to interface the flow of current lighting through the conductive to soil masses. This system is designed for lightning protection. Therefore, the grounding mechanism is primarily responsible for transmitting transient currents to the ground in which

neutralization takes place. These lightning currents have fast fronts, around a hundred nanoseconds, high amplitudes about tens of kA. In other grounding systems, power, and signals systems, the system must deal with fast transients in different cases other than its key objectives, providing a return route for fault currents/potential referencing. The system requires a low earth resistance of at least some ohms to prevent harmful potential increases for a long time. However, several well-known specifications define minimal earth resistance value to determine the suitability of a given ground system for the benefit of the field engineer/technical that uses the earth calculation of a system [1]. A very popular way of achieving low earth resistance is to use electrodes in conductivity enhancers, commonly referred to as backfill materials, particularly in highly resistive soils. Such materials have an advantage in providing excellent earth resistance in sites with exceptionally high soil resistance at confined locations. The improved material reduces the soil resistivity because the material might allow the soil to collect humidity from the surrounding soil and

keep its moisture in its structure. Several problems remain in the marketing of backfill materials as commonly used earthworks. The material can leak from the electrode district due to heavy rainfall, so refilling (or so-called recharge) may be an important necessity.

Moreover, it is also a question of the climate that needs to be answered when injecting this substance into the soil, particularly in built-on environments. As a treatment for the aforementioned defects of the backfill materials, the suitability of the mixed electrodes of bentonite was tested as a ground. Bentonite was chosen as a material for mixing with the electrodes implanted with the ground due to previous studies [2]. This work aims to find an optimal bentonite mixture for each grounding electrode connected as a ground network to protect the station from high and sudden currents under operating conditions. The parameters of these electrodes must be studied and verified, and taken into account, first, the most ideal and effective ratio of bentonite mixture with electrodes. Second, long-term variability of low soil resistivity. The safe current of person beings is computed according to human weight using certain equations. The present grid design incorporating step voltage, touch voltage, ground resistance, surge voltage and other parameters are determined by IEEE Std. 80-2000/2013. The value of the grounding measured in multilayered complex geology is often less than the calculated grounding value. The numerical increment of grounded grids and grounded copper rods is not cost-effective. The investigation in the soil grid must be done carefully to achieve an acceptable safety and optimum outcome due to varied soil characteristics at each substation. In this paper, the results obtained suggest that bentonite is more efficient in reducing grounding resistance by comparing and analyzing the collected data. As for the neutral point in the three-phase network, it is connected to resistance or the ground to prevent the occurrence of the high tension of one of the phases when any failure occurs between the phase and the ground, and for other purposes, including protection against short currents and stability of the network [3]. To minimize the losses that may arise, a security scheme should be investigated due to these problems and ensure greater safety. Often, the electrical system is prone to failure for many reasons.

One important explanation is unsuitable grounding. For an engineer to predict the fault causing in electrical systems, continuous monitoring and data availability are required. In the grounding trap, the key issue is the failure to hold the humidity at high temperatures on the earth's surface. The bentonite solves this dilemma based on the grounding as one of the defensive systems. Often, they briefly explain the difference between ground and earth, which implies that any mass that has referring voltage is determined by the bodies of other forces which are not to be the ground. We can now describe the grounding as the mass that electric current can get by connecting to the body with an effort equal to zero for the rest of the system [4].

This paper contributes the following aspects:

- Ensure the voltage of the electrical equipment in the station does not exceed the permissible limits.
- Maintain the step potential for the workers in the event of any faults or leakage current. It is also vital to discharge all the charges resulting from lightning strikes on the ground.
- Reduce the ground resistance of the station to the lowest possible value and making it optimally to ensure easy passage of fault currents.
- Reduce the number of electrodes, and thus the length of the conductive wire used in the implementation of the station's ground network will decrease, which will lead to a decrease in the total cost of these networks.

The organization of this paper is as follows: Section 2 introduces electrical grounding systems and grounding system types. Section 3 explains grounding resistance and bentonite clay. Section 4 gives the proposed methodology. Section 5 gives results and discussion. Finally, Section 6 summarizes the conclusions and future work.

## 2. ELECTRICAL GROUNDING SYSTEMS

The purpose of electrical grounding systems is to link the point of neutrality that connects the connectors of the power systems that convey the current to the earth. Initially, non-grounded systems will be explained and compared.

### A. Ungrounded Systems

Since the power transporter lines have a capacitance value and various potential, these structures are linked to the ground by condensers, as shown in Fig. 1. It can be seen that there are three currents ( $I_R$ ,  $I_Y$ , and  $I_B$ ) that are equal to  $V/X_c$ , where  $V$  is the voltage phase, and  $X_c$  is the capacitive phase compares to the earth. If these currents are equaled a current is not found to be neutral. The voltage is following these currents by 90 degrees [5]. When there is no-fault, the biasing of the load flow will be under balance load and the biasing voltage is near zero. For example, if there is a ground fault on line B, as in Fig. 2.

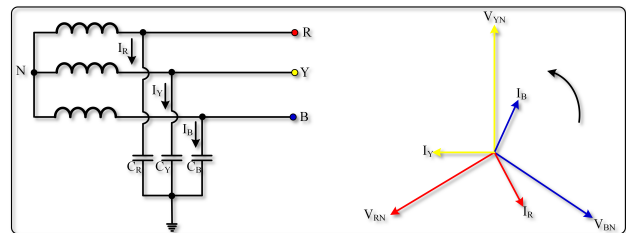


Figure 1. Ungrounded neutral system

The currents passing through the condensers ( $I_R$  and  $I_Y$ , which then enter the fault generate two voltages ( $V_R$  and  $V_Y$ ) follow the currents as capacitive impedance by 90 degrees of phase [6] according to Equation (1) and (2).

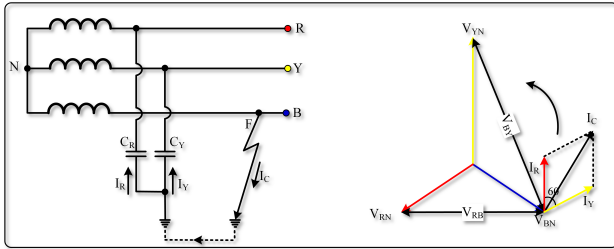


Figure 2. Fault in an ungrounded system

$$I_Y = V_Y/X_C \tag{1}$$

$$I_R = V_R/X_C \tag{2}$$

The short circuit current  $I_{s.c}$  is the summation of phases of the current as in Equation (3).

$$I_{s.c} = \sqrt{3} \cdot \sqrt{3}V/X_C = 3V/X_C \tag{3}$$

Faulting can have consequences on ungrounded systems:

- Because of the number of currents that will influence nearby communication stations, creating an electric field.
- The current is increases of fault line by triple compared to the standard case.
- The capacitive charging increases by  $\sqrt{3}$ .
- In comparison with the same condition, the voltage of the remaining two lines would rise 1.73%.

### B. Grounded Systems

In such systems, when the short circuit occurs, the current flows into the ground then to the bias point N, which has the same ground voltage. The following problems will be dealt with:

- The non-shorter phases voltage is not increased due to the bias point attached to the earth.
- Dump the ground arch and reduce the problem with contact.
- Enhance the safety system output and promote its use.

There are three grounding systems [7] in compliance with international standards IEC 364 and the French framework NFC 150-100. Two letters are specified for each system and the models are as follows.

#### 1) TN System

It is connected to the ground by the neutrality of the sources. The construction of the electrical appliances is combined with the neutrality of the source or the source of the device that is in turn connected to the ground, where

the letter T refers to the basis of the neutral, the second letter N which symbolizes the neutral relation of the equipment [8]. For this form, there are three kinds:

*The separate type TN-S:* where S indicates separate, the two connectors PE and N are split in this relation. Many countries across the globe use this method. For circuits with small or similar sections 10 mm<sup>2</sup> conductors, the TN-S method should be used. Fig. 3 shows the relation method for the IEC 364 TN-S earthing system.

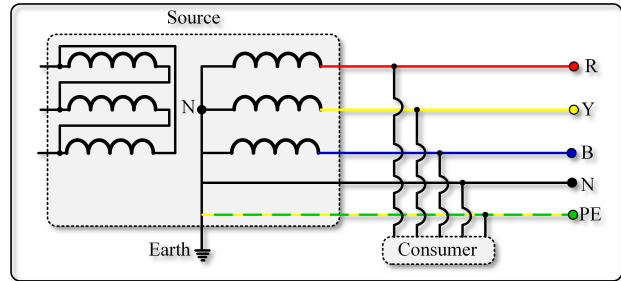


Figure 3. TN-S separate system

*The common type TN-C:* The consumer's point of the base is linked by a protective grounding conductor (PE), which can be an external conductor or metal covering to the neutral point of the feed transformer, so we can assume that its grounding line (Earth) is associated with the neutral line as in Fig.4.

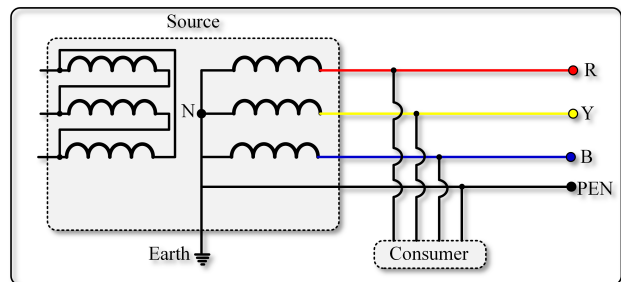


Figure 4. TN-C (common system)

*The grounding TN-C-S system:* In this case, two functions of the ground line and the neutral are joined together in the TN-S system, whereas in the TN-C system, the connecting line (N) and ground line G are connected from the source to enter into the consumer and are separating inside the home of the consumer. Multiple earth security protective (PME). Where the source is at several points and where a pole is required in or near the customer's facilities, the PEN conductor is referred to as the protecting conductor and the ground as a combined neutral and earth conductor (CNE) according to Fig. 5.

#### 2) IT system

The aircraft and ships with high resistance use this system and it's used in such instances because none of the

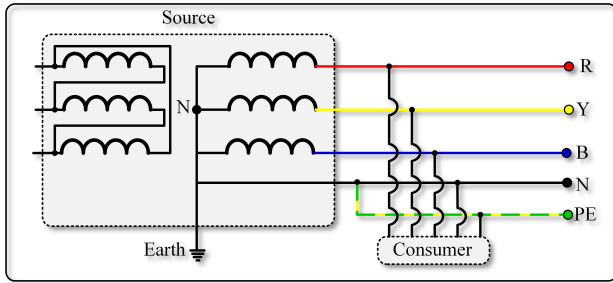


Figure 5. TN-C-S system

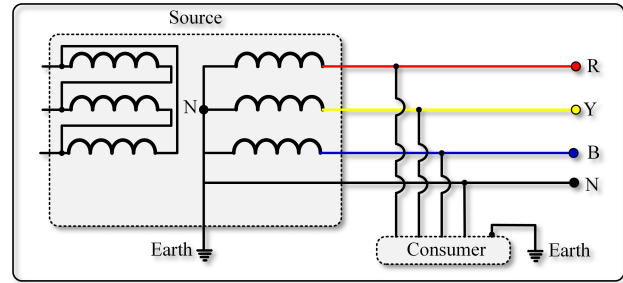


Figure 7. TT system

conductors have a connection to the earth as in Fig. 6. This system includes a single device that tracks isolation and provides an alarm when it reaches the threshold case. In surgery rooms can also be used this system [9]. The letter I is an independent word indicating that the power source and earth are not related, while the letter T is coming from Terre, which is a French word, means there is a direct I between earth and user.

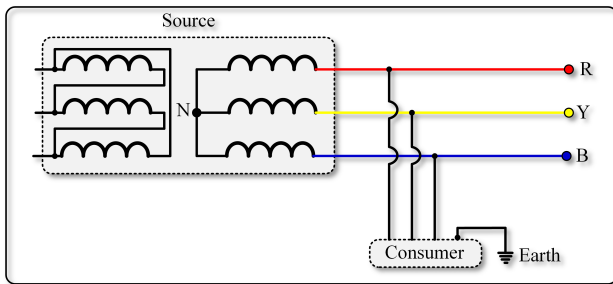


Figure 6. IT system

### 3) TT system

The main advantage is the high and low frequencies of the various devices connected to the system do not interfere. Furthermore, the problem of cutting the N point to the ground is avoided. Special wireless and wireless communications systems use this system for these advantages [10]. Each T indicates Terre, but the first T implies a connection between the power source and the earth. The next T, like the IT system means a joint between the earth and consumer point. In this system, the grounding in the consumer side works no matter what occurs on a source site as in Fig. 7. Table I shows the difference between all grounding systems in the electrical network.

## 3. GROUNDING RESISTANCE AND BENTONITE

### A. Grounding Resistance

The importance of grounding resistance is central to the grounding system's success or failure. If this resistance is relatively high, the voltage charge to the ground is not discharged, and therefore its risks being generated to escape the grounding network [11]. The following meanings must be indicated before addressing the importance of this resistance:

**Ground tension:** This is the possible difference between the earth and the comparable soil since the current passes through the soil.

**Seam tension:** It is part of the voltage of the earth which the human body will shorten. Suppose the resistance ranges from 1300 - 2000 in the human body. Therefore, an intensity value of 50 mA is adequate for the mortality of an individual whose current passes through his body. In this case, should be determined the importance of quantifying voltage that is dangerous for human life [12] according to Equation (4) and (5).

$$U_B \leq I_m \times R_m \quad (4)$$

$$U_B \leq 50/1000 \times 1300 \Rightarrow U_B \leq 65V \quad (5)$$

where:  $I_m$ , and  $R_m$  represent the current on human life, the minimum resistance to the human body respectively.  $U_B$  represents body contact potential. Therefore, it was necessary to consider these values when designing the ground network. Must not be the total value of the grounding resistance allow the formation of more than 65 V for a period of less than 1 second [13], [14] as in Equation (6).

$$I_E \times R_E \leq 65 \quad (6)$$

where:  $I_E$ , and  $R_E$  represent the current and resistance of earth respectively. This resistance consists of the sum of the partial resistances of the earth (propagation resistance) and the ground conductors that connect between them. Fig. 8 shows the relationship between the length of the electrode ( $l$ ) and the earthing electrode resistance ( $R_A$ ) in different soil resistivity ( $\rho\epsilon$ ). The following factors play a role in determining the value of the grounding resistance [15].

- Earth's specific resistance.
- The shape of the ground outlet.
- How to connect elements.
- Area of spreading the ground outlet.

TABLE I. Comparison of all grounding systems

Earthing system conditions	TN-S	TN-C	TN-C-S	IT	TT
Earth fault loop impedance (EFLI)	Low	Low	Low	Highest	High
Needs of grounding rod	No	No	Optimal	Yes	Yes
Risks of N cut	High	Highest	High	No	No
Safety	Safest	Least safe	Safe	Less safe	Safe
PE cost	Highest	Least	High	Low	Low
Interference	Low	High	Low	Least	Least
Risks	Broken neutral	Broken neutral	Broken neutral	Double fault overvoltage	High loop impedance

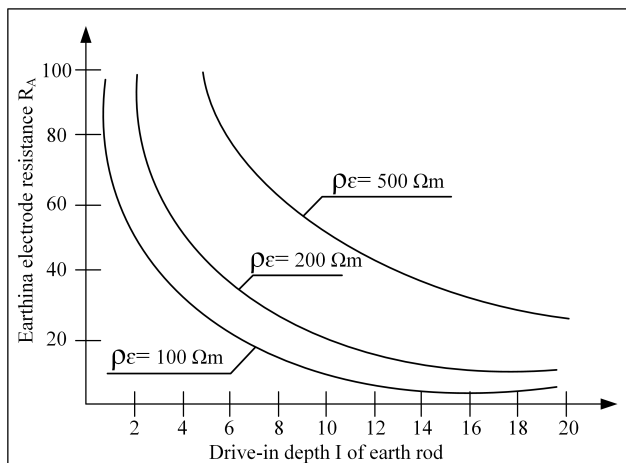


Figure 8. Influence of the length of the electrode on the resistance in different soil resistivity

### B. Bentonite Clay

Bentonite is a mineral generated by vitreous volcanic ash de-vitrification. This material is a dry powder and wet moist in natural clays and features high water absorption capabilities that cause them to grow and swell. Bentonite consists primarily of sodium-activated montmorillonite, which swells to the original volume mass when combined with water in dry conditions several times. The clay mineral of a class is called smectites. In addition to montmorillonite, bentonites can contain several accessory minerals and include less of other minerals, including kaolin, mica, illite, and non-clay minerals such as quartz, feldspar, calcite, and gypsum [16]. The consistency and applications of bentonite depend on whether any of these minerals are used in low quantities. Its density varies according to quality, with a range between 2.2 and 2.8 g/cm<sup>3</sup> when dry. Apparent bentonite density varies between 1.5 and 1.8 g/cm<sup>3</sup> when quartered and stacked in natural moisture state. The apparent density of milled bentonite products varies from 0.7 to 0.9 g/cm<sup>3</sup> depending on the fineness of a mill. Table II shows the chemical elements of bentonite used [17]. Where SiO<sub>2</sub> Silicon dioxide, also known as silica, Al<sub>2</sub>O<sub>3</sub> Aluminium oxide, CaO Calcium oxide, Fe<sub>2</sub>O<sub>3</sub> Iron (III) oxide or ferric oxide, Na<sub>2</sub>O Sodium oxide, MgO

Magnesium oxide, or magnesia, K<sub>2</sub>O Potassium oxide is an ionic compound.

The most important properties of bentonite for which it is employed in many different industries are the following:

- Water absorption and swelling.
- Viscosity and thixotropic of aqueous suspensions.
- Colloidal and waterproofing properties.
- Binding property.
- Surface properties (coagulation– absorption – adsorption).

### 4. PROPOSED METHODOLOGY

The proposed methodology of this paper is according to the following steps: **Step1:** Choosing distribution substation/s. **Step2:** Designing the ground networks as a letter T-shape. **Step3:** Simulating of all ground networks using ETAP program after entering all parameters. **Step4:** Implementation of all ground networks on-site by planting several electrodes and a copper conductor. **Step5:** Measurement of the grounding resistance of each station. **Step6:** If the value of the grounding resistance is greater than 1ohm. **Step7:** Bentonite material must be added to the ground networks. **Step8:** Re-measured the grounding resistance after a certain period.

#### A. Simulation of Ground Networks by ETAP

The eight chosen substations 33/11 kV are studied by the effect of bentonite on these substations of different dimensions of the grounding network. In addition, the far distance between those substations 33/11 kV for each other. The clear difference is in the specific soil resistivity of the selected substations 33/11 kV, which serves to measure the value of the grounding resistance and ensure the success or failure of the grounding network. Those resistors' performance was studied utilizing an earth tester device and the simulations of these networks through the ETAP 16.0.0 beta software and the reference standard for designing IEEE Std. 80-2000/2013. The study case for the substations 33/11 kV contains an ambient temperature of 40 °C, human weight, fault current to ground, current division factor, and X/R ratio. All substations 33/11 kV are applied to analyze the electrical network grounding mechanism and demonstrate its efficiency and protection within the electricity network.

TABLE II. The bentonite's chemical elements

Components	$SiO_2$	$Al_2O_3$	$CaO$	$Fe_2O_3$	$Na_2O$	$MgO$	$K_2O$
%	58.64	15.24	4.48	3.96	3.22	2.39	1.02

A sample was taken to simulate substation 33/11 kV number 2 as a model because the earth resistivity value of this station is greater than it can be compared to the rest of the other substations 33/11 kV. The T-shaped form has been drawn to keep the distance between conductors and the shortest conductor length has been achieved. The model needs eight ground rods distributed at each outer corner where the result of the simulation was presented in Fig. 9.

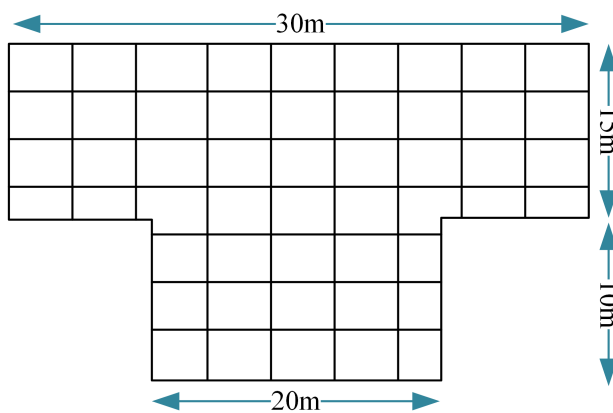


Figure 9. The grid frames

The model T-shape of grounding grid design is considered optimal due to the length conductor minimum is used. this model was simulated using ETAP package software. In the design, parameters data were entered such as spacing distances, grid depth, soil and crush rock of resistivity, conductor diameter and electricity parameter and the number of rods as shown from Table III.

### B. Procedure

In the protective system, grounding is highly crucial. A conductor's choice should take into with the following considerations: conductivity, strength and resistance due to corrosion. Furthermore, the used conductor should have strong long-term dependability but in one condition not too costly. The electrode of copper meets the characteristics listed above. The researchers confirmed that the galvanized steel grounding system has a grounding resistance that is lower than the copper grounding system, as the galvanized steel resistance is lower than copper. The equivalent ground resistance is close to zero, but it isn't easy to achieve this condition. According to the international standards international electric code (IEC) and national electric code (NEC), the grounding resistance should be 1 or lower. According to grounding systems, the resistivity of the soil used in this research according to its type and the degree of humidity ranges between (100-500  $\Omega$ m). The T-shape was used in the

implementation of the selected substations because it is the most economical design based on the conductor length and electrodes that utilized the steel galvanized by copper with a diameter of 25 mm<sup>2</sup> and a length of 2 m. These rods were connected through a copper conductor of diameter 120 mm<sup>2</sup>, the size of the suggested grounding system has been reduced, which ranges of (18-22) electrodes at 8 test sites. Table IV shows the locations, network areas, and the number of electrodes for each station. Where A is the total area, L is the length of the substation and W represents the width of the substation 33/11 kV. The welding process was carried out for all joints by heat (blasting welding) using the Gunpowder material. Soil conductivity is improved by the method of chemical treatment by adding about 30 kg of the bentonite material at least 30 cm from the electrode and a depth of 30 cm as shown in Fig.10. Also, bentonite material is added along the conduction wire between the electrodes without touching those electrodes through different quantities. The soil mixture should be pumped into the conductor path to avoid leakage or bentonite exit to ensure exclusion of entering the air and when done the route filling should be buried.

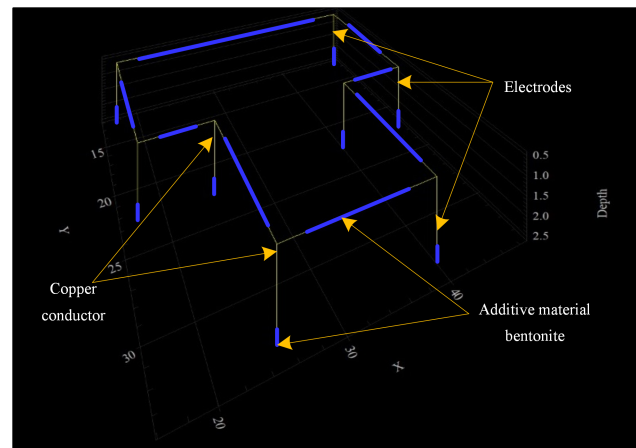


Figure 10. Three dimensions side view T-shape of grounding pit with additive material and electrodes

The results that will appear should compare before and after adding bentonite material. The ground resistance is practically measured utilizing a compact earth tester HANDY GEO through measurement of the six electrodes were taken regularly from each substation 33/11 kV as shown in Fig. 11, where  $d_1$ ,  $d_2$  is 20 m. These electrodes were projected to a specific area of the substations 33/11 kV for the eight different substation placements with geometric dimensions tested by the ETAP program and check the ground resistance.

TABLE III. Parameters of ground grid systems implemented in ETAP simulator

Conductors		Rods		Soil editor		
Type	Copper annealed soft-drawn	Type	Copper annealed soft-drawn	Surface material	Clean limestone	
Depth	0.5 m	Diameter	2.5 cm	Top layer	(100-500) $\Omega$ m	
Size	120 mm <sup>2</sup>	Length	2 m	Lower layer	$\leq 100$ $\Omega$ m	
Conductivity	100%	Arrangement	In grid corners	-	-	

TABLE IV. Substation locations, areas, and number of electrodes

No. of Substation	Location North / East	Network area (A = L.W) m <sup>2</sup>	Number of electrodes
1	36.292 / 43.221	40*30	22
2	36.340 / 43.134	30*20	18
3	36.356 / 43.112	35*20	19
4	36.323 / 43.135	40*20	21
5	36.334 / 43.125	40*25	20
6	36.319 / 43.116	40*40	18
7	36.285 / 43.212	40*30	21
8	36.389 / 43.066	45*30	22

TABLE V. Grounding resistance for all stations measured in simulation and locally

No. substation	Results from ETAP software			Results measured practically		
	$R_E$ ( $\Omega$ ) before bentonite	$R_E$ ( $\Omega$ ) after bentonite	Decrease resistance (%)	$R_E$ ( $\Omega$ ) before bentonite	$R_E$ ( $\Omega$ ) after bentonite	Decrease resistance (%)
1	1.586	0.351	77.86	1.602	0.394	75.38
2	2.133	0.626	70.65	2.260	0.706	68.73
3	1.932	0.412	78.67	2.023	0.453	76.54
4	1.772	0.375	78.83	1.960	0.402	77.27
5	1.616	0.363	77.53	1.781	0.395	75.53
6	1.136	0.298	73.76	1.390	0.320	71.76
7	1.346	0.359	73.32	1.496	0.391	70.95
8	1.362	0.365	73.20	1.567	0.378	72.20

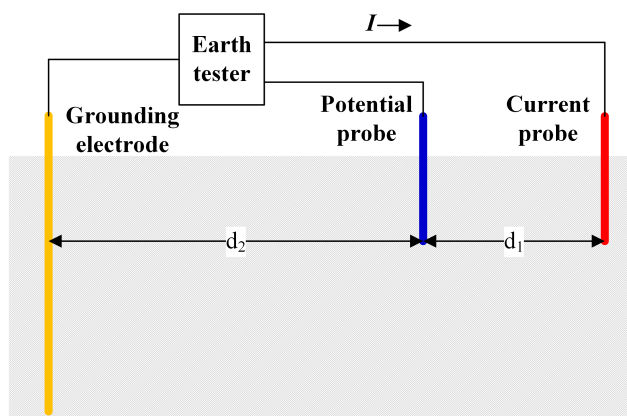


Figure 11. Ground resistance testing

## 5. RESULT AND DISCUSSION

Within 30 days, the grounding resistance measurement was completed practically. The values obtained for the grid resistance is less than 1 as shown in Table V and through the results that emerged from simulating the ground network of all selected substations 33/11 kV as shown in Table V, it is possible to notice a very great convergence for values between them with a minimal error rate due to the sensitivity of the measuring device used. The results confirm that the effect of bentonite on the soil in all substations 33/11 kV is very huge due to the very low value of the grounding resistance of these stations at a rate ranging (70%-78%) from the previous value without using bentonite material, whether the soil is wet or dry soil. Note that all the resistors values of these stations are within the applicable standards.

From the findings, this resistance-stabilizing capability is an essential feature of any backfill materials for grounding

purposes regardless of resistance reducing capability. Outcomes of this research will be of vital role and importance in preparing future research on grounding high resistance-reducing agents. Bentonite shows to be a chemical organic material that performs noteworthy success in reducing the grounding network's earth resistance when used basically.

## 6. CONCLUSION

The electrical network grounding systems are explained and compared to the standard systems IEC and NEC. It shows that the ground systems demonstrate an impact on the safety and efficiency of electrical networks. This paper has aimed at three objectives of which: The first objective is to design a safe, technically acceptable and economically viable grounding grid. The second objective is the number of the electrodes from the steel galvanized by copper used least possible. The third objective is the reduction of the grounding resistance value of less than (1) in grounding networks through the use of bentonite material in the grounding pit everywhere and operating to the comparison, characterization, and field examinations of these earthworks. The traditional grounding method is substituted for chemical earth. The theoretical and practically measured results prove the chemical grounding mainly serves the high resistance grounding hole requirement also this material has the property for moisture retention for a long time. The eight testing stations 33/11 kV demonstrated that the value of the grounding resistance was within a range of international standards, which indicates that the grounding will protect people from high voltage. Even if one of the stages has an issue such as the high earth fault, the network can remain in the working position. In the future, this work can be improved by employing optimization algorithms in uniform and non-uniform grounding grids to calculate the touch voltage and step voltage at the lowest value allowed and accepted in the ground network and increase the number of substations 33/11 kV.

## ACKNOWLEDGMENT

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**Hamsa F. Thanoon** received her B.Sc degree in Electrical Engineering from the Electrical Engineering Department, Communication and Electronics in 2007, University of Mosul. The M.Sc degree in Electrical Engineering, solid-state from the Electrical Engineering Department, the University of Mosul in 2010. She is currently working as an assistant lecturer in the Electronic

Department, the College of Electronics Engineering, University of Ninevah. She has several national and international publications to her credit. Her research interests include solar cell systems, microelectronics.



**Layth F. Kamal** received the B.Sc degree in electrical engineering from the Mosul University, Iraq, in 2005, the M.Sc degree in Electrical Engineering / Distribution Networks from the Department of Electrical and Electronic Engineering, University of Turkish Aeronautical Association, Ankara, Turkey in 2017. He is currently an Assistant Chief Engineer in the State Company of the North Distribution Electricity, Ministry

of Electricity, Iraq. He has worked in many positions in this company since 2006. Lastly, the communication department- the operation and control department and the substations department 33/11 kV. His research interests include distribution networks, electrical power system protection and artificial intelligence.



**Firas M. F. Flaïh** received the B.Sc. degree in electrical engineering from Mosul University, Iraq, in 2005, the M.Tech. degree in electrical and electronics engineering from the Sam Higginbottom University of Agriculture, Technology and Sciences, India, in 2014, and the Ph.D. degree in electrical engineering from the Huazhong University of Science and Technology, China, in 2017.

He is currently a Chief Engineer works with the State Company of the North Distribution Electricity, Ministry of Electricity, Iraq. His research interests include distribution networks, distributed generators, and smart grids. He is also a reviewer of many respected journals, including the IEEE TRANSACTIONS ON SMART GRID, the IEEE TRANSACTIONS ON POWER SYSTEM, the IEEE ACCESS, and the International Journal of Numerical Modelling: Electronic Networks, Devices and Fields.