World Applied Sciences Journal 12 (10): 1708-1714, 2011
ISSN 1818-4952

Effect of Multilayered Ground System on Substation's Surface Potential Distribution in Short Circuit Conditions Using Quasi Static Image Method and Method of Moments

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Abstract: Regarding the soil geophysical structure in most regions, to analyze soil system, one completely homogeneous model can not be used for the soil. Therefore in this paper, we have analyzed the ground system, considering the soil environment as a nonhomogeneous environment with multi layer structure because, with regard to the low range power frequency and the post size limitation, we can relinquish the electro magnetic propagating term in relation to the current on the soil network structure. We can consider the magnetic field as a quasi static field and therefore to analyze the multilayer soil system the quasi static images method has been used together with the moment method which has caused the increase of the analysis speed of the soil system considerably with its very good accuracy. In this paper, the substation's soil structure, while the ground network lies in the first layer and also in condition where the ground is covered with another material like snow and, the ground network lies in the second layer, are studied.

Key words: Ground system · Multilayer soil · Quasi static images method · Moment method · Step voltage

INTRODUCTION

In order to analyze ground system from the potential distribution method point, due to penetrating current to the soil and finding other safety parameters like step voltage and also determining the ground resistance, we must at first obtain, the method of the current distribution on the ground structure. The location of the ground network and its figure are elements in which affect the current distribution on the ground network structure. Considering the overall shape of the ground structure in different places, it has been observed that with penetrating the ground, soil type and following that related parameters like conductivity, electrical transmission will change. Therefore to consider multilayer ground system in order to analyze the ground system is unavoidable.

Dawalibi [1] for the first time discussed the current distribution on the ground structure and electro magnetic fields created by ground network currents. The self impedance of the buried conductors and the opposite induction effect in which is due to the conductors being close to one another in the ground network, has been considered. It has been mentioned in the paper that no discussion has been put forward regarding movable metal conductors.

Mader and Zaffanella [2] have presented an electrical network model and formulas in a distribution system to calculate resistance and self inductance between adjacent conductors. In that paper opposite inductance has not been considered for adjacent conductors with same length, confined and leaking currents. After that, Selby and Dawalibi [3] emphasized on the leaking currents in the buried and overhead conductors. Of course, in this method, the current distribution method remains constant in each conductor. That means to calculate current distribution on buried metal structures, it has been assumed that distribution in all parts are the same. This method is not suitable to calculate the current distribution for complex structure of every ground network conductors and will not have a desirable answer. Huang and Kasten [4] presented new model to calculate currents distribution, in ground system and as well as in metal conductors, considering the voltage drop in the length of the ground network conductors. In any case, leakage currents and ground network currents are considered separately in the calculation and their opposite effect and ground capacitance coupling effect has not been considered.

Alamo, Cidras and Otero [5] introduced a model for calculating the current distribution in the ground system. This model is based on electrical circuit theory and uses

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node method for solution, which in that considers the opposite induction and capacitance coupling effect between these leaking currents in the conductor length. But in this model the ground is modeled as a uniform environment and generally is not agreeable to the reality.

In IEEE80 [6], the ground network is a square network which is in a uniform soil. The existence of limitations in conductor numbers, network depth and network symmetry and also uniform current distribution in the conductors of the network has caused lowering of the calculation accuracy and not being able to use it in all considered situations. Also in IEEE2000 method, although the current distribution method in conductors has been considered non uniform, but the ground layers effect has not been considered directly and only the equivalent resistances has been used for this purpose. While this method gives suitable ground resistance answers in the calculation, but in calculating other related parameters like voltage profile, does not have a good accuracy.

Shahrtash has been engaged in introducing a method based on analytical relationships to calculate resistance and voltage of the ground system accurately which is able with designing the system in two different depth, reduces the ground network resistance considerably [7]. Using moment method, he has calculated ground system parameters including ground resistance. Considering the conductors resistance and their opposite resistance, has obtained the current distribution in the ground network and on that bases has calculated the potential on the ground [8].

In this paper in order to consider the real conditions governing the ground issue and regarding the time, other methods consider ground system analysis in the situation of short circuit conditions, considering ground structure as a one multilayer environment and also currents leakage effect to the ground, by benefiting from modified static photography method which in the area of the power frequency, has a very close response for ground system analysis, has been engaged in introducing a method with respect to faster analysis with desirable accuracy in analyzing the ground system in different layers.

In the suggested method the integration equation to moment matrix equations alteration techniques and benefiting from exponential expansion has been used. It is noteworthy that exponential expansion considerably will increase the speed of the calculation of the moment method in relation to the other methods mentioned above.

Theory

Problem Formulation: Ground network, generally, is made of a series of wire conductors (in the form of a cylinder) in which can be placed in the ground in any direction.

Thin wire here is the relation between radius and the length of the wire in which the radius must be very smaller than the length of the wire which this condition is true for most wire electrodes.

We assume that, ground conductors network are buried completely in the multilayer ground with soil conductivity σ and the air is also completely insulating and its conductivity is zero.

At the beginning, the ground conductivity structure is segmented and each segment is considered as one element. Using more numbers of element result in more accurate results but causes programs to be more time consuming. Of course we must create an optimum balance between these two parameters. In this paper each conductor is divided in to 8 parts and the results are calculated with a good accuracy (Fig. 6).

In ground system, the relation between penetrating current to the ground and produced potential arising from that, are related through the integral equation below [6].

$$\varphi = \sum_{k=1}^{N} \int G(r,r')I_K \; d\, l_k = 1/4\pi\sigma \sum_{k=1}^{N} I_{K/1k} \int 1/r_k d\, I_k \qquad (1)$$

Where G is the necessary Green function resulting from the effect of each segment current on ground network conductivity structure on created field in each point in space. In the above relationships φ is the electrical potential in any point in space, I_k is the current in each segment, r_k is any point distance from space, l_k is each segment length and σ is the environment conductivity.

Considering Green function it can be seen that the above integral equation can't be solved easily. Of course by using the moment method [5] and using point conformity, the above integral equation will be as follow:

$$[\, I \,] = [\, Z \,]^{-1} [\, V \,] \qquad (2)$$

The above matrix includes ground conductivity effect and its elements opposite impedances between ground network segments together or between segments and different points in space.

For the congenial conductive environment, z matrix is calculated as follow:

$$Z_{jk} = \int l_j \int l_k \, G(r,r') \, dl_j / l_j \, x \, dl_k / l_k = 1/ \, 4\Pi\sigma \, l_j \, l_k \int l_j \int l_k \, 1/r_{jk} \, dl_j \, dl_k \qquad (3)$$

Where l_j is the j_{th} segments length and l_k is the k_{th} segment. We must notice that the environment used in the above equations are infinite and congenial while in most cases we are faced with multilayer environment. By using the modified static image we can solve this case with good speed and accuracy which will be explain later.

Modified Quasi Static Image Method and Obtaining Green Function: The main objective in simulating ground system is finding elements in Z matrix in the equation [2], when the ground is taken in the form of multilayer environment, the Z matrix elements are calculated rapidly through modifies static images. To do the calculation, at first, Green function must be obtained. The Green function is used in order to calculate electrical potential caused from a point current source in the conductive congenial environment in any point [1].

In multilayer environment to obtain related Green function, after dividing the ground network conductors into small segments with the assumption of uniform current distribution in each segment, each segment is considered as a point current source. By using the geometric light method, each point current source is considered as a light source [3].

In a way that by the light radiation from each source and its conjunction with different environmental boarders, the light ray is divided in two. One is the light that passes the boarder and enters a different environment and the other is the ray that is reflected by the fringe to the same environment including the source.

Each ray with α coefficient is reflected inside the primary environment and with â coefficient enters the secondary environment. Fig. 1 shows this case.

4-a $I_{21} = \alpha_{12} i_{1/1}$: $\alpha_{12} = (\sigma_1 - \sigma_2)/(\sigma_1 + \sigma_2)$
4-b $i_{1j} = \alpha_0 i_{2,j-1}$: $\alpha_0 = (\sigma_1 - \sigma_0)/(\sigma_1 + \sigma_0)$
4-c $l_{2j} = h + l_{i,j-1}$ from the zone 1 & 2 borders to the down below direction
4-d $l_{1j} = l_{2,j-1} + h$ from the zone one to the upward direction

By using the above method of solution for the below environment, we reach the figures in Fig. 3.

So, by locating the point current source static images, the multilayer is transferred to a congenial environment with layer conductivity which the point current source is inside and by using Green function relationship in homogeneous environment, the voltage can be obtained in any point in space.

In general condition, considering the form of the problem, we must calculate Green function from the point of view of point current source location and the location that we want to obtain the field.

Whereas, in this method by finding the images with the relative algorithm the voltage in any point in space can be obtained only by using one Green function which is the same Green function in the congenial environment (eqn. 5).

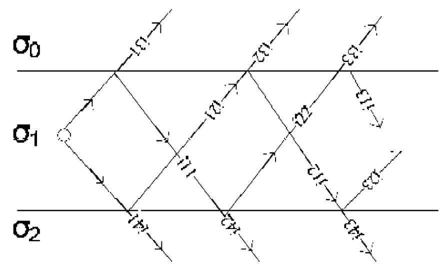

Fig. 1: The method of static image production by the geometrical light method in the situation that the conductor is in the first layer.

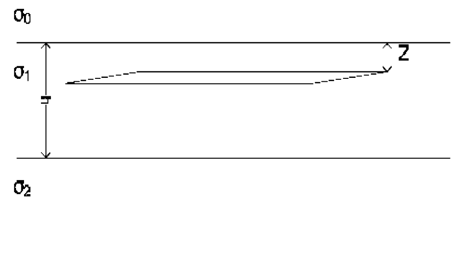

Fig. 2: Configuration of ground layers and the location of the network

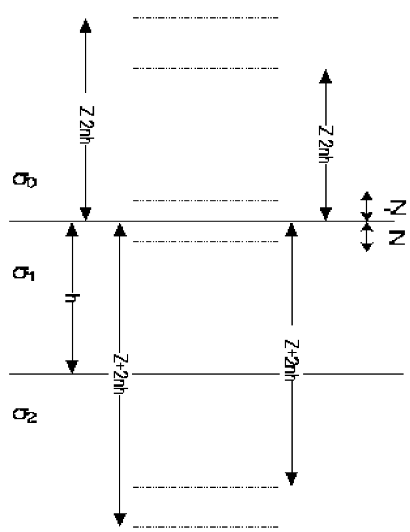

Fig. 3: The location of static images in the situation that the ground network is in the first layer

$$G(r,r') = 1/(4\pi\ \sigma)\ |\ r-r'\ | \quad (5)$$

Where, r is the position vector of a point which voltage is found and r' is the position vector of the point current source. In the case of two layered ground the closed form of Green function considering the images size and position are as follow which are the same with the [8] method.

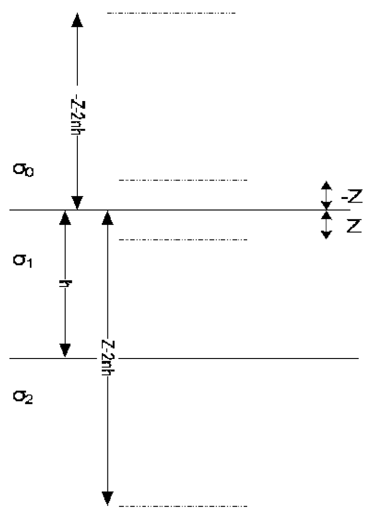

Fig. 4: The position of static images in condition that ground network is in the second layer

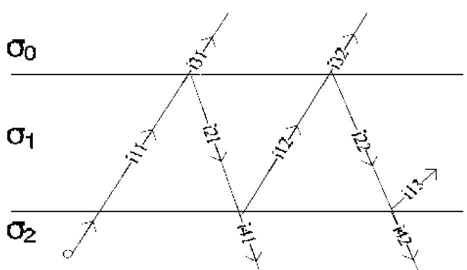

Fig. 5: Method of creating static images by geometrical light method in condition that the conductor is in second layer

$$G= 1/4\Pi\ \sigma_1\ [\ 1/r_0 + \sum_{N=0}^{Inf} [\ k^n/r_{n1} + k^{n+1}/r_{n2} + k^{n+1}/r_{n3} + k^{n+1}/r_{n4})]$$

ρ is the position vector in the cylindrical coordinates of each current element, Z and Z' are the ground and air separating distance for each point in space and point current source respectively, h is the first layer depth and H=2nh.

If we consider a condition that the ground surface to the height of h is covered with different materials, for example, a condition where ground is covered by snow, the ground layer is located in the second layer.

In other words, the current source is in the second layer. The related static images are obtained as follow:

And related Green function is equal to the no. 7 equation.

$$G= 1/4\Pi\ \sigma_2\ [\ 1/r_0 + \sum_{N=0}^{Inf} [\ k^n/r_{n1} + k^{n+1}/r_{n2})] \qquad (7)$$

Where:

$$R_{n1} = [\ \rho^2 + (z+z'+H)^2\ ]^{1/2} \qquad \text{7-a}$$

$$R_{n2} = [\ \rho^2 + (z+z'+H+h)^2\ ]^{1/2} \qquad \text{7-b}$$

In general, finding the Green function related to a structure like this which at first, current elements static images on the ground network or an algorithm that explains the connection between images, is more used in the case of structure with layering. Then, the complete problem is considered as a congenial environment with current elements static images, which by using the congenial environment Green function (eqn. 5), for each images, the Green function for the whole structure is obtained.

Assessment and Results: In order to evaluate the methods used in the ground system analysis the obtained results are compared accurately to electromagnetism method. In electromagnetism method, the ground network is considered as a series of wire antennas and by using Maxwel equation governing the thin wire in multilayer environment in the frequency zone, the numerical solution of the integral equation, the electrical type, is done.

The high accuracy of this method, has accredited it as a suitable reference for results comparisons [10].

The studied case, is a ground network according to the Fig. 6 in the 60x60 m dimension where each length, contains 4 meshes that in a ground structure containing two layers with conductivity 0.005 for the first layer (upper layer) and 0.00125 for the second layer which the thickness of the upper layer is 4m and a current equal to 1000 amps. Is injected to the ground and the ground network is in two different conditions in this ground structure.

First condition is related to a power post which is assumed that the ground network is placed in 0.5m depth and inside the first layer.

In this paper, we have obtained the potential distribution on the ground area. The obtained results by the paper are presented in Fig. 7 and the results obtained from electromagnetism are in Fig. 8. As it can be seen, the results of the two methods are in agreement. Resulting step voltages from this potential distribution on the ground area are presented in Fig. 9.

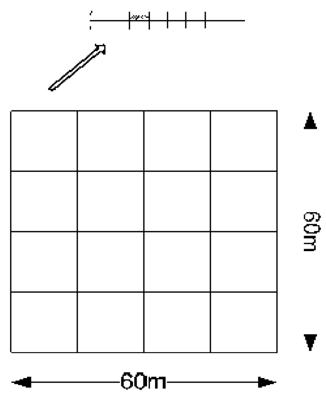

Fig. 6: Ground network structure and its dimensions

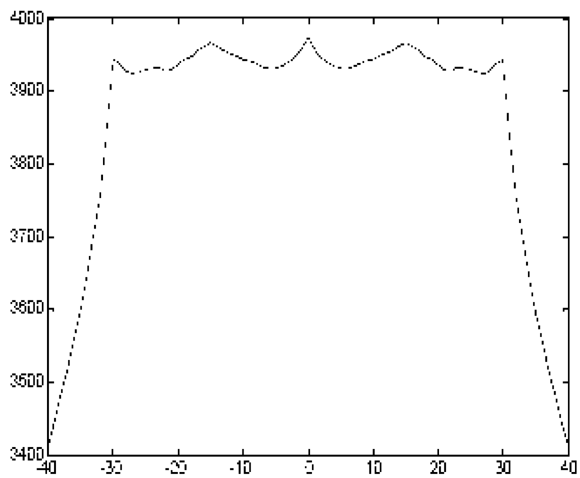
Fig. 7: Voltage illustration on the post ground surface in terms of the distance from the center of ground network by the static images method

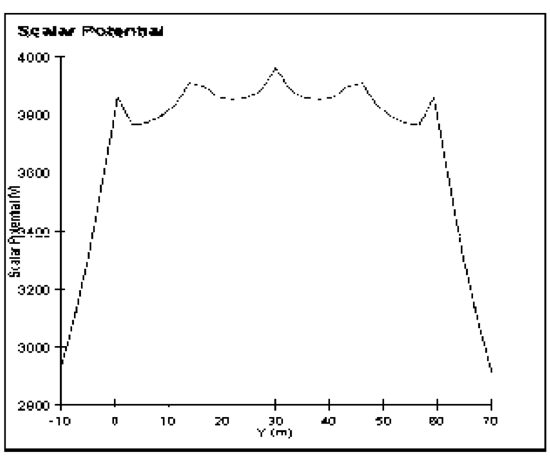

Fig. 8: Voltage illustration in terms of the distance fromthe edgeof the network by the electromagnetism method

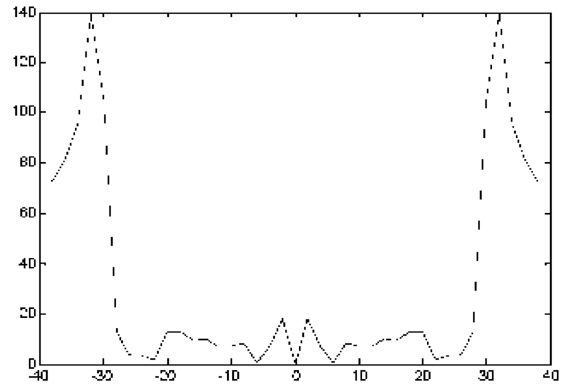
Fig. 9: Step voltage illustration in terms of distance from ground network center by the static image method

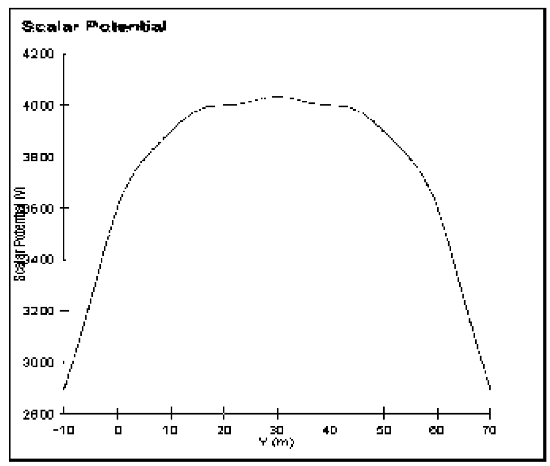

Fig. 10: Voltage figures in terms of distance from the edge of the electromagnetism method

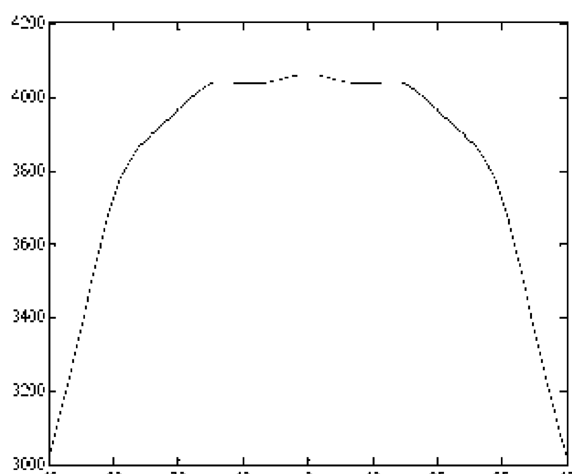
Fig. 11: Voltage figures in terms of distance from the center of the network by the SIM method(static image method)

Table 1: The related ground network quantities in two conditions

60x60, including 16 meshes	Network dimensions (m)
In the first condition,0.5 In the second condition, 4.5	Depth of the network location (m)
0.015	Conductor diameter (m)
0.005	Specific conductivity upper layer (s/m)
0.00125	Specific conductivity(s/ m)
4	Upper layer thickness(m)

Table 2: Position and the size of the image for the current source in the first layer

Image position	Image size
-Z	1
Z+ 2nh	K_n
Z- 2nh	K_n
-z+ 2nh	K_n
-z-2nh	K_n

Table 3: Position and the size of the image for the current source in the second layer

Image position	Image size
-Z	1-k
Z-2nh	$(1\text{-}k)k^n$
-z-2nh	$(1\text{-}k)k^n$

In the second situation, the potential distribution in a power plant environment has been studied in a condition that the ground is covered with different materials. The practical example for this case is when the ground surface is completely covered because of snowing.

In this condition, the ground network is buried in 4.5m depth under the first layer and inside the second layer. Also with the assumption of ground surface covering materials conductivity equal to 0.005 and ground conductivity equal to 0.00125, the potential distribution on the covering material is obtained by the electromagnetism in the Fig. 10 and by using static images method in Fig. 11.

As it can be seen, the two methods results have acceptable conformity which confirms the authenticity of the obtained results in the article. In Tables 1-3, the coefficient and the parameters quantities related to the images resulting from ground structure elements current first and second conditions (eqn. 6 and 7) are presented respectively.

CONCLUSION

In this article by using the static image method, multilayer environment is modeled in two different conditions. One in condition like power post which in those, the ground network is in the first layer and the other one in a condition like the power plant grounds where the ground is under pile of snow or a factors that can be accounted as an upper layer for the ground (that is The ground being in the second layer and we calculate the potential on the upper layer) and the results were compared by electromagnetism method.

It can be seen that using modified QSIM besides using moment method, is a suitable estimate for the ground system analysis calculations in the multi layer environment and power frequency, which will present the intended answer with noticeable reduction in calculation time and with desirable accuracy.

To obtain the current distribution on the ground structure which it may be positioned in each of the ground layers, by benefiting from modified QSIM and by obtaining the images of each current elements on the ground structure, the multilayer environment is transferred into a homogeneous environment and by only using congenial environment Green function and using the moment method, current distribution on any ground structure and potential distribution in each of the ground layers are obtained.

The compiled software is able to obtain current distribution on any type of ground configuration and any form of ground networks. Using this software, potential distribution, step voltage, electrical field distribution and ground resistance can be obtained in a very short time and also in the ground system designing process, the effect of each above factors can be easily studied.

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