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Transient Behavior Modeling And Analyze Of a High Voltage Laboratory Earth System

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Abstract

New high voltage laboratory earth system perform in order to achieve to the goals like, Creating a low impedance path back to Earth for the test equipment, Limiting the potential of different components in laboratory in a permissible limit, avoids of Creating noise in measurements during testing and safety. Requirements for design and implementation of high voltage laboratory grounding system are different from other parts like Electrical substations, power plants and buildings. This paper investigates the modeling and analysis of transient behavior of High Voltage Laboratory earth. First we consider several values for soil resistivity in different deeps; an appropriate model for the soil is extracted. After this step, different parts of Laboratory earth System Are imported in CDEGS software which is a Specific modeling and analysis of transient behavior of the Earth systems, and after that the Study of different earth plans like adding earth rods, the mesh size and the electrode mounting plate (well earth) is presented.

Keywords: High Voltage Laboratory. Earth System. Transient Behavior. CDEGS.

1. Introduction

Earth system is one of the most important issues that should be considered in design and establishment of high voltage laboratories. Earth system of a high voltage laboratory should provide following objectives:

Should provide a return path for earth currents and prevents measurement errors caused by noisy currents during the impulse (voltage and current) tests. In order to protect

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electrical equipment, should damp electrical impulse through a low impedance path rapidly, so that high Currents discharge in the earth effectively. In this way the potential remains within the permitted level, should secure the safety of people who work in the laboratory. This task will be done by decreasing step and contact voltages to values lower than permitted range of related standards. Firing (starting) impulse generators in HV laboratories causes flowing transient currents whose amplitude are big and in rage of some KA and also have high (sharp) slopes. These currents are being injected to earth system in special spots which is normally due to occurrence of spark (arc) in under test equipment. Thus components which had earth potential during permanent operation will have high voltage. Flowing such currents create voltage gradient on the surface dependent to the earth impedance. Then several problems may occur such as [2]:

- Occurrence of arc or damage in laboratory control system due to high potential difference.
- Measurement errors during tests due to releasing current in cable sheath.
- posing a hazard by not grounded metallic equipment for laboratory staff.

Ideally, the best earth system consist a good conducting plate which makes a same potential level parallel to the surface and also provides the return transient current path. of course this kind of earth system has its own problems as a big metallic plate cannot be easily put in the concrete. also implementation cost of this case would be too much. Therefore, there are some replacements for this kind of earth system whose most important are mentioned in the bottom [3]:

- Metallic plate can be put on the surface in a way that cover regions related to impulse tests. This case has advantages such as: less cost, easier replacement, direct access, removing corrosion problem, and possibility of using copper, Aluminum, or brass as the

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plate. In contrast, there are some disadvantages in using metallic plate on the laboratory ground surface as well, such as:

- The test region will be limited to that plate
- Laboratory building will not be faraday cage anymore.

For this reason, a mesh network of conductors and bars will be used under laboratory floor (similar to what exist in substation ground) for this kind of plate arrangements and metallic plates will be connected to this network.

- in the other method in modern high voltage laboratories, a kind of arrangement is used for such an earth system in which a copper network embedded in floor concrete along with several bars (beaten to the ground) is used. Availability to the earth network to connect to equipment is possible through some branches in shape of risers connected to wide screws which are distributed in test salon. bars and copper network should have strong and proper connection to each other.

The second proposed replacement is little more costly than the first one but its important advantage is that whole of laboratory ground surface can be used as test area and laboratory building would be faraday cage.

The Earth system behavior in dc, low frequency (power frequency) and high frequency (lightning surge) states are studied by many researchers [4]. Several computerized analysis based on circuit theory [5]-[7], transmission lines theory [8]-[9], electromagnetic fields theory [10]-[11] and combined methods [12] are developed.

Furthermore, softwares such as CYMEGRD, ETAP ground module, DIgSilent, etc are developed for investigation of earth system in low frequency state that mostly are considered for substation earth system design. Commercial and semi-commercial softwares such as CDEGS, WinIGS and TRAGSYS are available for transient analysis of earth system.

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Results obtained from transient study and simulation of a 400kV high voltage laboratory earth system is presented. Simulations are done in CDEGS 2009. Firstly Soil modeling is extracted based on the laboratory soil resistivity. Next, a impulse current wave is injected to the earth system based on impulse current generator position. Then different plans such as utilization of earth-well, increasing earth rods and mesh dimensions will be studied. Besides, the effect of different parameters change on earth system performance will be studied. Results will be analyzed and they will be used for finalizing the earth system plan.

2. Soil modeling in the laboratory

There are two main steps for determination of soil model in simulations. The first step is practical measurement of specific soil resistivity which is performed based on known methods such as WENER or Schelumburger. The next step is Interpretation of obtained results. For this purpose, called sounding curves can be used [13]. Besides, computer programs are developed for this purpose. RESIST program related to EPRI and RESAP program related to SES can be mentioned among them [14]. Schematic plan of supposed 400kV high voltage laboratory is shown in figure 1 and supposed soil layering in main salon is shown in figure2. Supposed Laboratory main salon dimension is 45*45 with the height of 32m. 16 earth Rods with the height of 3 meters and 16mm diameter is left during plan implementation in previous years. There is some earth-well outside of salon and in different corners.

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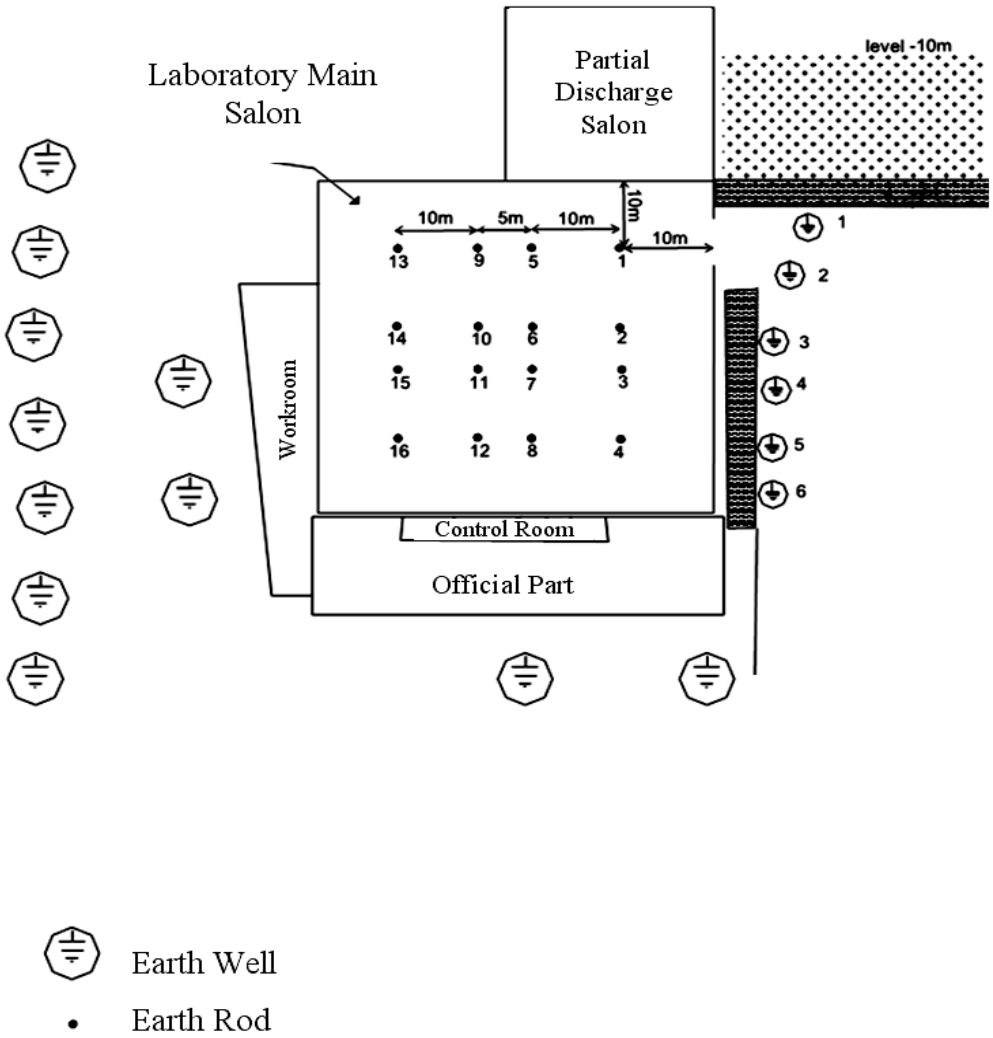

Fig 1: Schematic plan of supposed high voltage laboratory

supposed amount of Specific resistance is listed in table 1. ρ amount is low in surface layers. this surface layer is pertained to concrete. IEEE80-2000 standard [13] states that typical amounts of Non-reinforced concrete specific resistance is between 10^6 to 10^9ohm.m

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for in dry state and between 21 to 100 ohm.m in wet state. presented typical values of first state is for concrete dried by oven in laboratory. Specific resistance of concrete may be less while it is exposed to air due to moisture content. Furthermore, the aforementioned standard states that concrete is a Adsorbent of moisture. a concrete block buried in soil behaves like a semi conductor with specific resistance of about 30 to 90 ohm.m. This matter is an attractive issue in soils with medium or high specific resistivity as a wire or bar surrounded by concrete has lower resistivity than resistivity of similar electrode which is buried in soil directly. This phenomenon is similar to improvement of features of surrounded soil of an electrode. Ref [15] also states that specific resistivity of concrete varies from 40 to 5000 ohm.m and its typical value is 100 ohm.m.

It is proven that a metal placed inside of concrete makes an effective earth electrode. This phenomenon which known as Ufer has made an important role in grounding technology [16]. respecting to that phenomenon, the term FGS or Foundation Grounding System (structures formed from steel bars that have created a 2D or 3D structure, and used in buildings, factories, substation, and etc foundation) has become common [17]. Main salon soil layering is shown in fig 2.

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Table 1: soil model in study of earth system of laboratory main salon

Layer	Specific resistance	thickness of layer
Concrete	5	0.7
Soil	30	∞

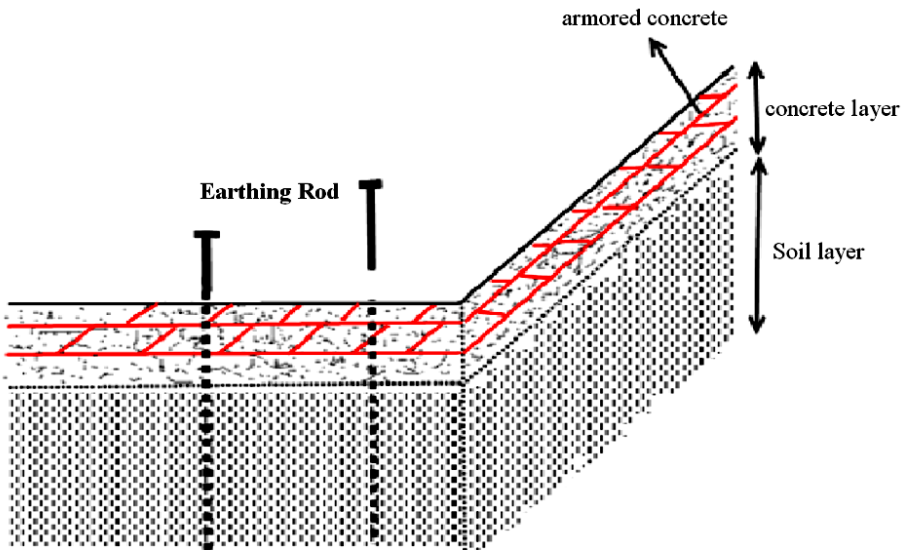

Fig 2: main salon soil layering

These structures are studied and analyzed in several literatures. Ref [18] has noted the specific resistivity of armored concrete around 1 ohm.m. With this interpretation, the specific resistivity of concrete in main salon (which is an armored concrete with 12 grade rebar and formed in two mesh layers with dimension of 20*20 cm and with 20cm distance) is considered 5 ohm.m.

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3. The current wavelet

There are some different methods for showing a wavelet such as standard, Heidler, and two exponential functions. Here, the investigated wave is a wavelet with a peak of 20kA and feature of 1.2 micro.sec (figure.3). two exponential functions can be written as follows:

$$i(t) = AI(e^{-\alpha t} - e^{-\beta t}) \quad (1)$$

Where α And β are constant parameters , and A is correction factor of wave peak. the method used in [19] has been for expressing of the standard wave in form of two exponential functions (proper for inserting to software).

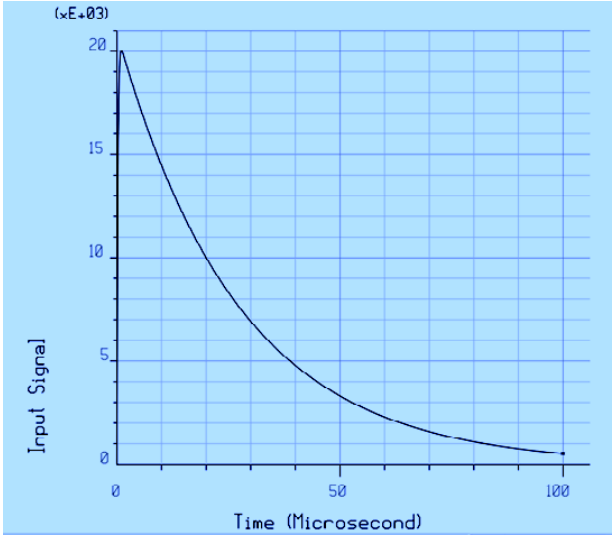

Fig 3: 20kA, 1.2micro.sec current wavelet

Finally the following values have been obtained using trial and error method for the mentioned feature:

$$\alpha = 36876.35 \text{ (s)}$$

$$\beta = 4933011 \ (s)$$

$$A = 1.0454$$

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4. Components of the Laboratory Earth System

Laboratory earth system is composed of elements with various shapes and materials such as ground annealed copper bars, copper conductors with rectangular cross section (copper belts) and galvanized steel elements. The modeling of different shapes of conductors in high frequency also has been studied by researchers. Equivalency of conductors with rectangular cross section (belt) and circular cylindrical conductors at low and high frequencies is true. the mentioned software in this paper has also used this Criterion for making copper belts and circular conductors equivalent. It should be noted that the reason of using belt conductors with high width and low thickness instead of circular conductors in laboratory is due to less inductance of this conductor and consequently less earth system impedance in high frequencies[20]-[21].

Generally, using belts (high width and low thickness), conductor with higher cross sections, current splitting (using T, star , etc connections), and also shortening of conductor length are of effective practical factors in inductive reactance reduction of earth electrode.

Earth rods with 3m length and 16mm diameter are made of soft copper. Copper strip used in projects with 100*1 mm dimension is made of soft copper. Rebars have not been considered in the project now. Building structure has not been considered as well.

5. Simulation

There were 16 earth rods in basic plan and also 1*1 m copper mesh in 0.2m depth from ground surface has been installed. Figure 4 shows basic design. the collision location of impulse current is middle of network, considering layout plan of test equipments in laboratory main salon.

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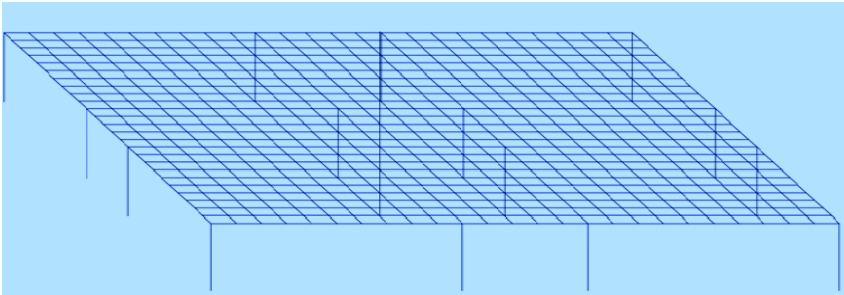

Fig 4: Basic design of HV laboratory earth system (1*1 m mesh)

In order to evaluate the voltage gradient in different depth, a number of profile Plates have been defined to calculate earth system parameters (such as potential). Three profile Plates in depth of 0, 0.7m, and 3m have been defined. According figure 5, the number of points in each profile is 13*13.

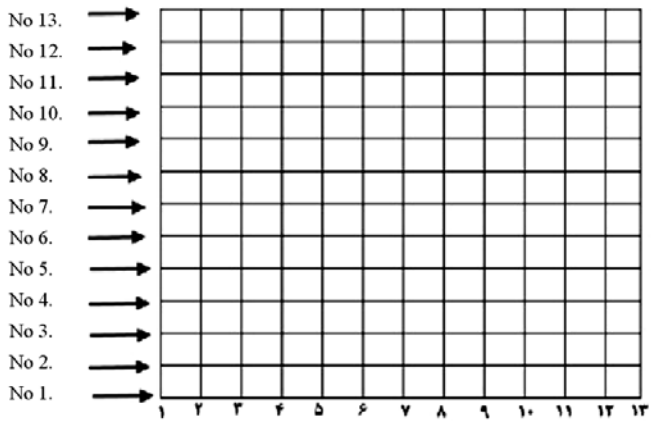

Fig 5: Points in a defined profile

Figures 6 to 9 show results of spatial distribution of max transient potential on the ground surface in different times. Results show the difference between voltage profiles in different times. High voltages have been firstly created in the discharge location and then they have been spread more uniformly in whole of the surface and their value decrease

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gradually. The maximum transient time is 5μs. After that voltage has been spread in whole of surface.

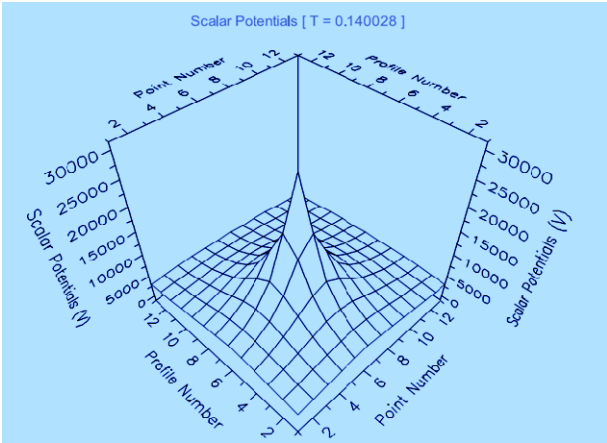

Fig 6: Spatial distribution of max transient potential on the ground surface (depth z=0) in t=0.14 μs

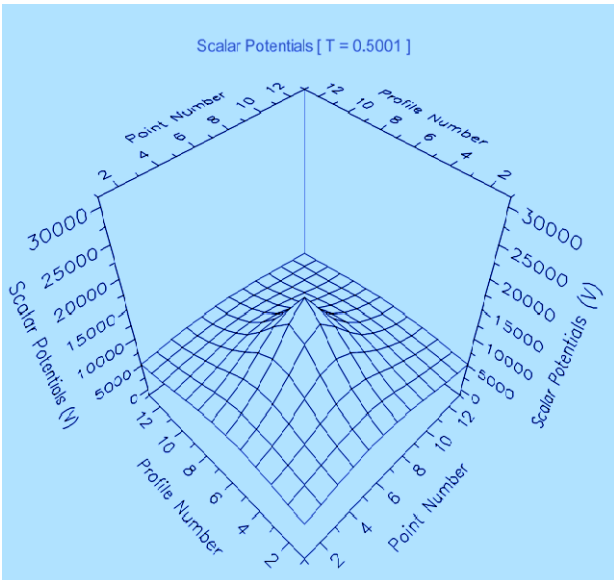

Fig 7: spatial distribution of max transient potential on the ground surface

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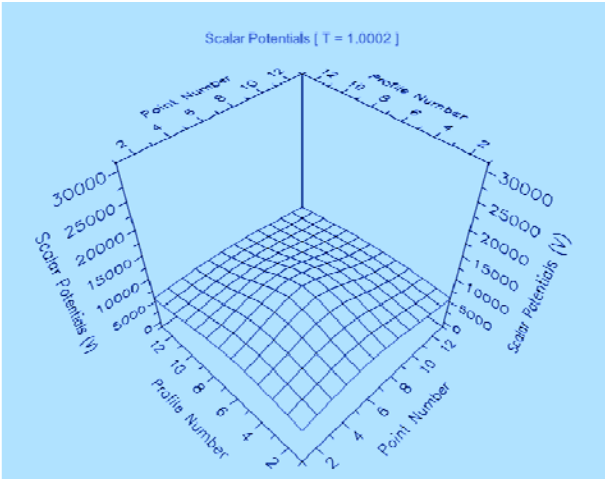

Fig 8: spatial distribution of max transient potential on the ground surface

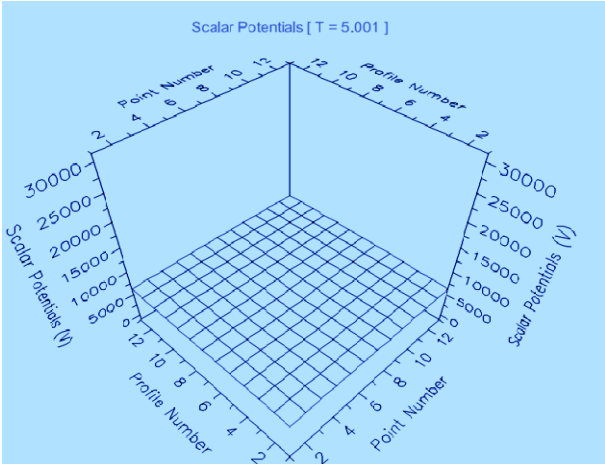

Fig 9: spatial distribution of max transient potential on the ground surface

The max transient potential rise or TGPR1 has been created before impulse current reaches the maximum value in discharge location (approximately 0.14 μs). In this time, voltage and current waves are spread in a small region around discharge point. No action and reaction between other sections of system have been done during this time.

[1] - Transient Ground Potential Rise

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The max potential in the ground surface, figure 10 (from point1 to point13 of profile1, points 14 to 26 of profile 2 and in the same way to the last) is drawn to more accurately show the figure 7 which is the peak of potential distribution. it can be seen that the max potential value on the ground surface is about 30kV.

Figures 11 and 12 show peak of maximum transient potential in depth of z=0.7m and z=3m respectively. in these cases the max potential reach 20kV and 9kV respectively. it can be seen that as depth increases, high frequency current tends to flow in low depth near to the surface. This phenomenon can be justified as same as skin effect phenomenon.

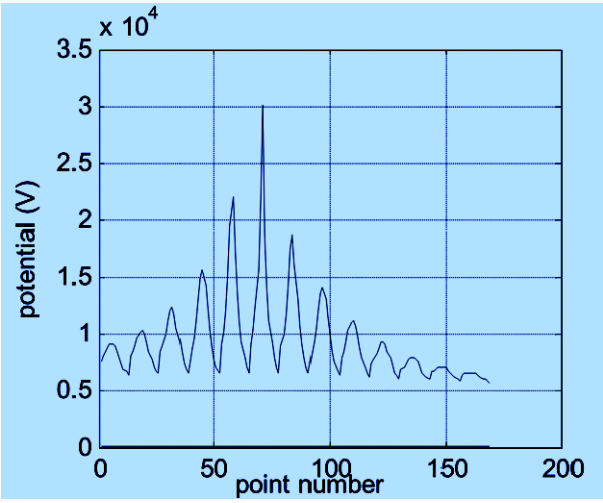

Fig 10: the peak of maximum transient potential in different profiles (depth z=0m)

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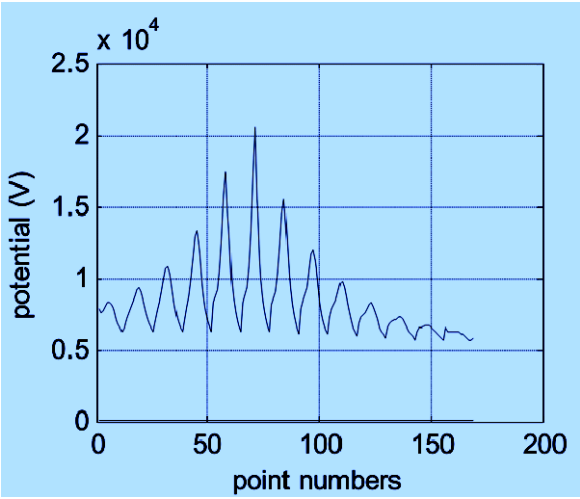

Fig 11: the peak of maximum transient potential in different profiles (depth z=0.7m)

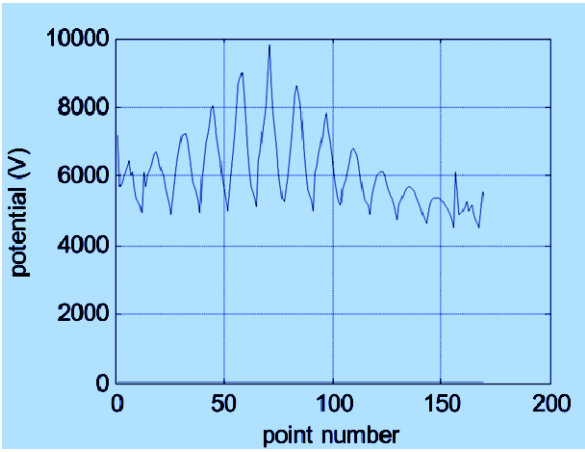

Fig 12: The peak of maximum transient potential in different profiles (depth z=3m)

Table 2 shows a summary of results obtained from simulation. It can be seen that effect of choosing dimension of copper mesh in this design is considerable and increasing of their dimensions worsen the performance of earth system. The effect of installation of earth bars on transient response is low but their effect is more obvious in deep soils. Installation of earth-well considerably improves the earth system performance.

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Table 2: a summary of results obtained from simulation

Result of plan changing	Potential distribution ramp in the ratio of base state	Maximum Transient Voltage on the Ground (kV)		Characteristic / State
-	-	30		basic state
Relatively Significant negative effect	Increasing	32		Increasing mesh Dimension
Little positive impact, more influence in depth	Small reduction	28	Under state 1	Increasing number of Rod
Little positive impact, more influence in depth	Small reduction	29	Under state 2	
Little positive impact, more influence in depth	Small reduction	29	Under state 3	
Significant positive effect	Small reduction	28		Installation earth well
Significant positive effect	Significant reduction	9		Increasing rise time of impulse wave

Another important issue that should be considered is that the shape of current wavelet has a considerable effect on results. System transient response has been improved significantly with increasing of rise time of input signal or decreasing of signal slip in first moments.

Conclusion

This paper has considered modeling, study, and analysis of earth system transient simulation of an existing HV laboratory. Soil modeling has been done based on experimental measurement results. results show that using a design including installation of horizontal copper mesh inside of concrete with proper dimensions (affordable cost and enough for performance), putting some earth bar (respecting proper distance) in earth

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network external region, and installation of some earth-well can meet the requirements. Horizontal mesh has significantly affected on decreasing of potential spatial distribution peak and also potential gradient on the ground surface. Although bars have less effect, they are needed in order to keep the earth impedance stabilized through the year. Installation of earth-well has also improved distribution of potential in deep soils and it is cost effective as well.

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