A Stochastic-Deterministic Optimization Method for Eliminating the Environmental Impact Produced by a Grounding System

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Abstract. The method suggested by the Authors allows to design, in few steps, a grounding system which doesn't generate any dangerous area on the soil surface. It is based on the Maxwell's subareas method and consists in determining the points where the touch voltage is maximum, these points being determined by resorting to a coupled stochastic-deterministic optimization method. On the basis of these points the designing of the grounding system is carried out by means of the "Traveling Salesman" algorithm, until all the dangerous areas on the soil surface are entirely removed.

The method suggested allows to eliminate the expensive measurements which are usually taken on the spot on the soil surface involved by the grounding system as well as the asphalted areas of the soil, thus avoiding the environmental impact.

Key words

Environmental impact, optimization, grounding systems, Traveling Salesman.

1. The common designing method

The common designing of a grounding system can be summarized according to the following points:

- 1) On the basis of the value t_F of the time during which the fault persists, the designer must determine the permissible touch voltage U_{Tp} fixed by Standards on the basis of the well-known curve U_{Tp} versus t_F .
- 2) The designer chooses a grounding system as starting system (Fig. 1 shows an example of starting ground-ing system which will be examined in section 4).
- 3) The Maxwell's subareas method [1] [3] is applied to this grounding system in order to determine the probable dangerous points $P_{s max}$ of the soil surface where the touch voltage is greater than the maximum permissible touch voltage U_{Tp} .
- 4) If these points do not exist, the grounding system which has been chosen turns out to be good.
- 5) If there are a lot of dangerous points, the designer, according to his experience, must choose another grounding system and he must do all the abovementioned designing steps again, from point 3) on. On the contrary, if there are few dangerous points the designer can consider his design to be finished, providing that the soil surface areas containing the dangerous points are asphalted. Obviously this involves an environmental impact.

2. The designing method suggested

The method carried out by the Authors, which automatically chooses the grounding system at each designing step so as to speed up the whole designing process, lies in:

- 1) finding all the points $P_{s max}$ of the soil surface where the touch voltages U_T (called source touch voltage U_{ST} by Standards) are greater than the permissible touch voltage U_{Tp} ;
- 2) connecting the nodes of the grounding system under examination with the points $P_{g max}$, these points being put vertically under the points $P_{s max}$ at the same depth of the grounding system (see Fig. 2).

The Authors have found that the new grounding system thus obtained has an earthing voltage U_E lower than that of the previous system, as well as the touch voltages are lower than the previous touch voltages [4].



Fig. 1 - The starting grounding system.



Fig. 2 - Points $P_{s max}$ (on the soil surface) and $P_{g max}$ (at the same depth of the grounding system) generated by the grounding system.

To sum up, the designing method proposed can be explained as follows. If the grounding system of the *i*th step doesn't turn out to be good (that is, if by applying the Maxwell's method there are on the soil surface some

dangerous points whose touch voltages are greater than U_{Tp} it is necessary to find on the soil surface all the points $P^{i}_{s max}$. This work is obviously hard since the designer, according to his experience, must determine by the Maxwell's program the dangerous points by a process of trial and error. This can be done very quickly by resorting to an ad hoc stochastic-deterministic optimization method carried out by the Authors in [5] and [6] and explained in paragraph 3.

Once all the points $P_{s\,max}^{i}$ relating to the whole soil surface are known, it is possible to determine the points $P_{g\,max}^{i}$ put vertically under the points $P_{s\,max}^{i}$. In this way, the new grounding system of the (i+1)th step can be obtained by connecting the nodes of the *i*th grounding system with the points $P_{g\,max}^{i}$.

To minimize the cost of the grounding system the Authors have resorted, in each step of the designing process, to the "Traveling Salesman" method. In this way the length of the connection conductors between the various points, that is between the "old" nodes of the *i*th grounding system and the new points $P_{g max}^{i}$, is reduced to the minimum.

The designing method is stopped when the grounding system under examination doesn't cause any more dangerous point $P_{s max}$ on the soil surface.

3. The Stochastic-Deterministic Optimization Method

The stochastic-deterministic method consists in two optimization methods which are cascade coupled [5] - [7].

The first one is stochastic and leads to the determination of the probable local maximum points; this method was developed by the Authors in [8]; it consists, in short, in carrying out a certain number of samplings of the objective function $U_T(P_s)$, each sampling being followed by a cluster analysis based on a suitable coefficient γ .

The second one consists in finding the true local maximum points, these points being obtained by applying the deterministic "quick" Hooke-Jeeves optimization method to each of the probable local maximum points found before [9].

Let's examine the two methods. Later on we will omitted for simplicity the subscript *s* from the points P_s of the soil surface.

A. The Stochastic Method

As we have already said, this method leads to determine the probable local maximum points of the touch voltages $U_T(P)$. Briefly, the method consists in a first sampling of the function $U_T(P)$. This sampling is made by considering a small number of points P(x,y) of the soil surface, these points being placed at steady intervals. Then the optimization process goes on with a series of selection steps of points. Each step consists of a cluster analysis followed by an "L-shaped thickening process".

Let's see at first how the selection of points *P* concerning the cluster analysis relative to the *i*-th step occurs. In this *i*-th cluster analysis a threshold value $V_{thr,i}$ must be chosen. This value is such that only the points *P* where $U_T(P) > V_{thr,i}$ must be selected to go on with the optimization process.

The threshold value is calculated on the basis of the minimum and maximum values of the function $U_T(P)$ which was found in the previous step, by the equation:

$$V_{thr,i} = (1 - \gamma_i) U_{T \min, i-1} + \gamma_i U_{T \max, i-1} \qquad i=1, 2, 3, \dots \quad (1)$$

where *i*-1=0 corresponds to the first sampling of the function $U_T(P)$.

The coefficient γ_i must be suitably chosen by the designer according to his experience [6]. In fact, the value γ_i establishes how much we want the threshold value must be close to $U_{T max, i-1}$.

The "L-shaped thickening process" concerning the *i*-th step consists in adding two other points P'_k and P''_k to each point P_k chosen by the *i*-th cluster analysis (see Fig. 3). P'_k and P''_k are L-shaped positioned compared to the point P_k and the distance between P''_k and P_k is half the distance between the points P_{k-1} and P_k found in the previous selection (see Fig. 3). It's all the same for the distance between P'_k and P_k . In this way we assume that the function $U_T(P)$ increases on the right of the point P_k and, as a consequence, the points P'_k and P''_k are considered to be good for the optimization process. On the other hand, should this not be the case, that is if the function $U_T(P)$ increases on the left of the point P_k under examination, the points P'_{k-1} and P''_{k-1} can be considered as good for the optimization process (see Fig. 3).

Usually, by applying the stochastic method, two or three selection steps are enough for determining the probable local maximum points, as we will see in the next section.



B. The Hooke-Jeeves optimization method

As is well-known, the Hooke-Jeeves optimization method for searching the maximum value taken by a function f(P), where P=P(x,y), goes on with "survey movements" and "pattern movements" to determine, step by step, points where the function to be optimized turns out to be bigger and bigger (maximum points).

Briefly, indicating with P_i the maximum point reached in the generic *i*-th step of the optimization process, the method consists in giving a "pattern movement" towards the point $P'_i = 2 P_i - P_{i-1}$. Having done this, "survey movements" are carried out around the point P'_i by changing its co-ordinates of quantities equal to $\pm h$ (the "survey movements" are marked in Fig. 4 and Fig. 5 with small circles). At this point there can be two possibilities:

- the "survey movements" around P'_i lead to a new maximum point P_{i+1}, such that f(P_{i+1})>f(P_i) (see Fig. 4). In this case a "pattern movement" towards the point P'_{i+1} is given and so on;
- the "survey movements" around P'_i don't lead to a new maximum point (see Fig. 5). In this case there are two possibilities: P_i can be considered as the final point of the optimization process (maximum point of the function under examination), or the optimization process must start again; in the second case, P_i must be considered as the new starting point, the quantity h must be reduced and new "survey movements" around P_i must be made.



Fig. 4 The "survey movements" around P'_i lead to a new maximum point P_{i+1} , such that $f(P_{i+1}) > f(P_i)$.



Fig. 5 The "survey movements" around the point P'_i don't lead to a new maximum point.

4. An example of grounding system designing

We intend to design the grounding system of a group consisting of a transformer room and two buildings. The grounding system must leak a current $I_F = 100$ A. According to Standards, a single grounding system must be realized for the whole group and, on the basis of the value of the time t_F during which the fault persists, the value of the maximum permissible touch voltage is $U_{Tp} = 75$ V.

Let's consider the grounding system shown in Fig. 1 as the starting one, this being constituted of three rectangular electrodes connected by an insulated conductor. Each electrode is made up of horizontal cylindrical conductors having a section $S = 50 \text{ mm}^2$ and is buried at a depth h = 0.5 m in a soil having resistivity $\rho = 100 \Omega \text{m}$. The sampling points of the function $U_T(P)$ as well as the iso-potential curves on the soil surface are plotted in Fig. 6. As everybody can see, the number of points of the first sampling is extremely low (16 points).

The results of the three cluster analyses are given in Fig. 7, 8 and 9. As you can see, at the end of the third cluster analysis, the combined application of Maxwell's method and stochastic-deterministic optimization method leads to the following results: 11 probable dangerous points are found; these points are marked with asterisks in Fig. 9, and the value of the touch voltage of these points is more than U_{Tp} .



Fig. 6 Stochastic method applied to the grounding system of Fig. 1: first sampling. The sampling points are marked with asterisks.



Fig. 7 Stochastic method applied to the grounding system of Fig. 1: 1st cluster analysis. The probable dangerous points are marked with asterisks.

At this point the Hooke-Jeeves optimization method is applied to each probable dangerous point. As a result, the 11 previous points are reduced to only 4. These 4 local maximum points are marked with asterisks in Fig. 10.



Fig. 8 Stochastic method applied to the grounding system of Fig. 1: 2nd cluster analysis. The probable dangerous points are marked with asterisks.



Fig. 9 Stochastic method applied to the grounding system of Fig. 1: 3rd cluster analysis. The probable dangerous points are marked with asterisks.



Fig. 10 Deterministic method applied to the grounding system of Fig. 1. The local maximum points are marked with asterisks. The maximum true point is P_{max} .

Finally the only true maximum point can be easily determined among these 4 points. This point is (see Fig. 10): P_{max} (7, 45), where $U_T(P_{max})=108.09$ V.

Since $U_T(P_{max}) > U_{Tp}$, it may be inferred that the grounding system under examination, that is to say that one in Fig. 1, doesn't turn out to be good.

At this point, it would be necessary to asphalt the areas where the dangerous points are localized; in this way the soil resistivity turns out to be very increased, so the touch voltages are reduced. Nevertheless this constitutes a strong environmental impact. Actually, in the case under examination, the maximum point P_{max} is in correspondence with a garden.

It is therefore necessary to design another grounding system. We can resort to the common designing technique, consisting in adding a further conductor along the circumference of the area under examination (see Fig. 11). In this way, all the dangerous points are removed, but the grounding system thus obtained is very expensive since the total length of the conductors is $L_t=360$ m.



Fig. 11 New grounding system chosen by resorting to the common designing technique (L_{i} =360 m).



Fig. 12 The final grounding system obtained by the designing method suggested in the paper ($L_t=271.53$ m).

On the contrary, if we apply the designing method suggested in this paper we need only three designing steps and the final grounding system turns out to be optimized. In fact, as regards the final grounding system of Fig. 12, the total length of its conductors is $L_t=271.53$ m; consequently the cost of the grounding system is optimized.

The grounding system of Fig. 12 has been obtained by connecting the dangerous points found in the three designing steps with the nodes of the starting system by the "Traveling Salesman" algorithm.

5. Results and conclusions

In this paper the Authors have suggested a new method to design, in few steps, a grounding system which doesn't generate any dangerous area on the soil surface. It is based on Maxwell's subareas method, stochastic-deterministic optimization method, and "Traveling Salesman" algorithm.

By way of example, the method has been applied to a simple grounding system of a group consisting of a transformer room and two buildings.

This method leads to costs which are much lower (more than 30%) than the costs obtained by the common designing method, and allows to eliminate both the expensive measurements on the spot, and, above all, all the ugly asphalted areas of the soil surface.

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