# New Methodology to Measure the Grounding Grid Resistance of Substations Applying Short Distance Among Electrodes

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**This paper presents the development of an analytical formulation which estimates the reduced position of the current electrode and potential probe used for measuring the grounding grid resistance of the substations located in urban areas. The methodology was validated using data from measurements made in an experimental grounding grid and subsequent field test measurements of large substation grounding systems. The results show the accuracy of the proposed novel method applied when the testing area does not permit large separations among the electrodes involved in the measurements.**

***Index Terms* — Fall of Potential Method, Grounding System, Grounding Grid Resistance, Urban Substations.**

## I. INTRODUCTION

PERIODIC evaluations of substation grounding grids are important to ensure the safety of workers and people walking near a substation during a ground fault in the power system.

The fall of potential method is commonly used for measuring the grounding grid resistance of the substation. Such technique is characterized by the existence of two auxiliary electrodes: current electrode (*D*) and potential probe (*X*). Fig. 1 shows the fall of potential method. The substation grounding grid is represented as a hemispherical electrode that has a radius *a.*

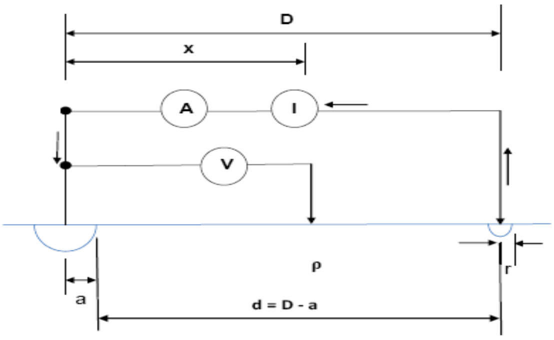

Fig. 1. Fall of Potential Method.

The ground resistance of an equivalent hemispherical electrode in a uniform soil with radius *a* and resistivity *ρ* is expressed by (1).

$$R_G = \frac{\rho}{2\pi a} \tag{1}$$

The voltage between the grounding grid under test and a generic point ***X*** on ground surface related to the current electrode at distance *D*, *V(x)*, is expressed as:

$$V(x) = \rho\frac{I}{2\pi x} - \rho\frac{I}{2\pi(D-x)} \tag{2}$$

It is possible to define the resistance at point *X*, *R(x)*, as:

$$R(x) = \frac{V(a)-V(x)}{I} = \frac{\rho}{2\pi a} - \frac{\rho}{2\pi}\left(\frac{1}{D-a} + \frac{1}{x} - \frac{1}{D-x}\right) \tag{2}$$

Consider ratio [1], (3) can be obtained and based on (4) the condition $R_G = R(x)$ is satisfied when $k(x) = 1$.

$$k(x) = \frac{R_G}{R(x)} = \frac{(D-a)(Dx-x^2)}{x^2(2a-D)+x(D^2-2a^2)+aD(a-D)} \tag{3}$$

$$R_G = R(x)k(x) \tag{4}$$

The procedure adopted is to obtain two curves: the measured resistance curve, *R*(*x*), and the corrected resistance curve, [*k*(*x*)*R*(*x*)]. The value of substation grounding grid under test is the point where the measured resistance curve and the corrected resistance curve intersect.

Fig. 2 shows the curve *k*(pu) *versus X*(pu) and indicates that for several values of *D* (0.75 x *diagonal* until 3 x *diagonal*) there are positions for the potential probes where *k*(pu) = 1.

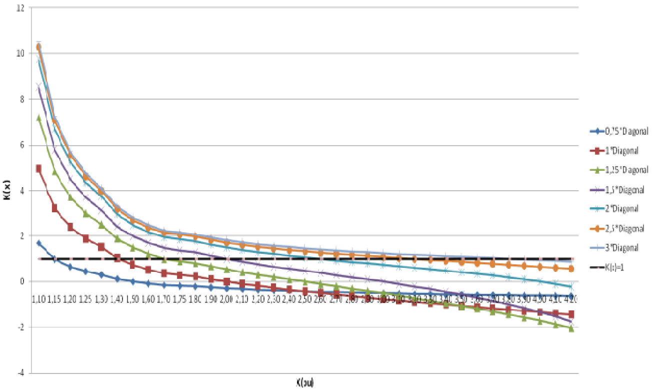

Fig. 2. *k(x)* versus *x(D-a)* expressed in pu system.

## II. MUTUAL COUPLING EFFECT DUE TO THE ELECTRODES PROXIMITY

It is possible to estimate the position where the potential probe should be placed in order to obtain the resistance value of the substation grounding grid under test. Fig. 3 shows the curve where the *x-axis* represents the relation *D/2a* (*D/diagonal*) and *y-axis* gives the ratio *X/D*. The curve in Fig. 3 forms a set of points where the measured and corrected curves intersect each other (points where $R_{MEASURED} = R_{CORRECTED} = R_G = R_{TRUE}$). Ideally, all the points in the referred curve should have the same value of $R_{TRUE}$. However, this does not occur because of the coupling effect due to the proximity of the electrodes. This coupling produces errors in the $R_{TRUE}$ value of resistances.

In the curve shown in Fig. 3, the existence of a tangent line from the point *D*/*diagonal* = 10 is considered. This point corresponds to the exact value of the grounding grid resistance ($R_{TRUE}$). Observing the other points in the curve shown in Fig. 3, tangent lines can be seen. These lines cross the *D*/*diagonal* = 10, as shown in Fig. 3.

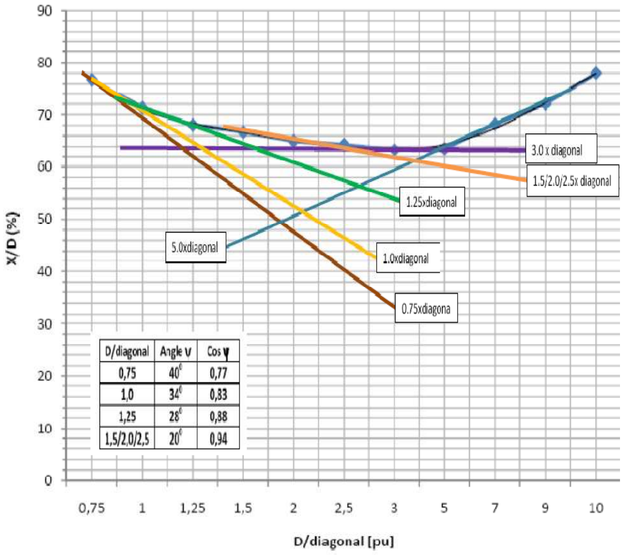

Fig. 3. Methodology to reduce erros.

The angle (*Ψ*) formed between each tangent line in Fig. 3 and the tangent line corresponding to the point *D*/*diagonal* = 10 represents how far the corrected value of resistance [$k(x)R(x)$] is the exact value of the grounding grid resistance. In other words, this is also the distance between the corrected and exact values of resistance. The projection the corrected value of resistance ($k(x)R(x) = R_G$) over the plane that contains the exact resistance value (*D*/*diagonal* = 10 tangent line) leads to a reduction of the error. Such projection can be carried out by multiplying the corrected value of resistance by the cosine of angle *Ψ*.

## III. MEASUREMENTS FOR MODEL VALIDATION

In order to validate the proposed model it is necessary to measure the ground resistance considering different distances between the grounding grid and the current electrode (*D*). Measurements were performed on an experimental grounding grid [2].

Fig. 4 shows the results considering ratio $D/2a = 0.75$ (that means $D = 10.61$m), where 22.8Ω is the intersection point between the measured and corrected curves.

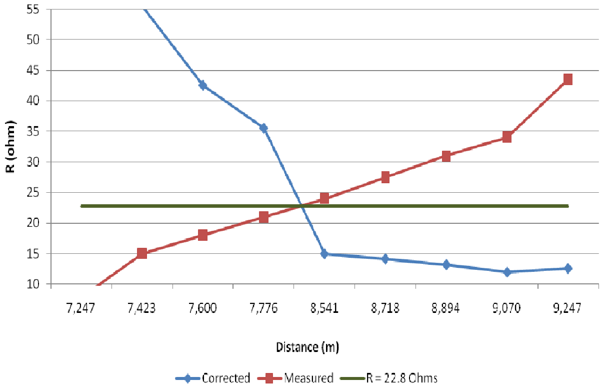

Fig.4. Measured and corrected resistance curves: 0.75 x diagonal.

Table I shows the results applying the referred methodology, considering various distances among the electrodes and soil characteristics.

TABLE I
COMPARISON OF RESULTS

| Soil type | D (Current Electrode distance) | $R_{Measured}$ (Ω) | $R_{Corrected}$ [k(x)R(x)] (Ω) | $R_{Projected}$ (Ω) | Error with correction (%) | Error without correction (%) |
|---|---|---|---|---|---|---|
| $\rho_1$=1179 Ωm | 10 x diagonal | 18,7 | 18,7 | ---- | ---- | ---- |
| $h_1$=7,9 m | 4,74 x diagonal | | 18,0 | ---- | 3,74 | 3,74 |
| $\rho_2$=16 Ωm | 3,33 x diagonal | | 20,0 | 18,8 | 0,53 | 6,95 |
| $h_2$= infinite | 1,9 x diagonal | | 20,0 | 18,8 | 0,53 | 6,95 |
| | 0,7 x diagonal | | 26,0 | 20,0 | 6,95 | 39,04 |
| $\rho_1$=845 Ωm | 10 x diagonal | 17 | 17 | ---- | ---- | ---- |
| $h_1$=3,1 m | 1,5 x diagonal | | 19,1 | 17,95 | 5,61 | 12,35 |
| $\rho_2$=144 Ωm | 1,0 x diagonal | | 20,5 | 15,79 | 7,12 | 20,59 |
| $h_2$= infinite | 0,75 x diagonal | | 22,8 | 17,56 | 3,29 | 34,12 |

## IV. CONCLUSIONS

The paper shows a methodology that permits to apply the fall of potential method with short distance among electrodes. For each measured value of resistance, correction factor $k(x)$ is applied and two curves are obtained: the measured resistance and the corrected resistance curves. The point of intersection of these two curves indicates the value of the substation grounding grid resistance. However, this value of resistance presents an error due to the proximity of the electrodes. In order to reduce the error a projection methodology was proposed.

There are errors in the measured values of resistance due to the proximity among the electrodes. However, after applying the corrections in the resistance (measured), the final values of resistance are acceptable both in theoretical and practical case.

Tests performed in experimental grounding grids confirmed experimentally the theoretical analysis. The application of hemispherical electrode to represent the grounding grid is valid as demonstrated by the field tests and computational simulations.

## V. REFERENCES

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