# Stray current induced corrosion in lightning rod cables of 525 kV power lines towers: a case study

F.R. Wojcicki*, M.E.M. Negrisoli** and C.V. Franco***

**Abstract**

With the growth of several areas in modern society, the necessity to generate and carry electrical energy to big cities has greatly increased. Cables supported by power towers with galvanized steel foundation usually carry energy. As the foundations are underground they may cause high rates of corrosion. These are usually detected by a conventional potential measurement using a $Cu/CuSO_4$ reference electrode. It is believed that corrosion results from stray currents that flow through the ground to close the loop between neighboring towers. Stray currents originate in the lightning rod cables of the power line towers, induced by the strong electromagnetic and electric fields of the energized power lines. The intensity and direction of those currents were measured, indicating substantial values of both their AC and DC components. The potential of the tower ground system, measured in the perpendicular direction of the main axis of the power line, was plotted as a function of the distance to the tower base. The results clearly indicated the tendency to corrosive attack in the anodic towers as reflected by the slope of the plot, whereas no signs of corrosion could be found in the reverse slope, confirming the visual inspection of the foundation. The profile of the potential plots could be changed providing the electric insulation of the lightning rod cable.

**Keywords** Corrosion. Stray current. Lightning rod cables. Power lines.

## Corrosión inducida por corriente perdida en cables de pararrayos de 525 kV en torres de energía: un estudio de casos

**Resumen**

Con el crecimiento de varias áreas en la sociedad moderna, la necesidad de generar y conducir la energía eléctrica a las grandes ciudades ha aumentado enormemente. La energía, normalmente, se transporta por cables sostenidos por torres de energía con base de acero galvanizado. Cuando las bases son subterráneas, pueden ocasionar altas tasas de corrosión. Éstas, normalmente, se detectan por la medida convencional del potencial enpleando un electrodo de referencia de $Cu/CuSO_4$. Se cree que la corrosión es el resultado de corrientes perdidas que fluyen a través de la tierra para cerrar el lazo entre torres vecinas. Las corrientes perdidas tienen origen en los cables de pararrayos de las torres de energía, inducidas por los fuertes campos electromagnéticos y eléctricos de las líneas de energía. La intensidad y dirección de estas corrientes se midieron, indicando valores sustanciales de sus componentes AC y DC. El potencial de la base de la torre, medido en la dirección perpendicular al eje principal de la línea de energía, se representó, graficamente, como una función de la distancia a la base de la torre. Los resultados indicaron claramente la tendencia al ataque corrosivo en las torres anódicas, como reflejado por la inclinación del gráfico, en el cual no fueron encontrados señales de corrosión en la inclinación inversa, confirmando la inspección visual de la base. El perfil de los gráficos de potencial podría cambiarse proporcionando el aislamiento eléctrico del cable de pararrayos.

**Palabras clave** Corrosión. Corriente perdida. Cable de pararrayos. Líneas de energía.

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## 1. INTRODUCTION

Outstanding industrial development requires the transport of considerable amounts of energy through long distances, which enhances the importance of the power lines as an essential link between energy generators and final consumers. With the increase of the voltage in the lines in order to minimize resistive losses, wooden and concrete structures have become inadequate, and have been progressively replaced by galvanized metal ones. Galvanized structures are designed to last up to 12 years in aggressive environments or even 24 years in the country side[2-4]. Their foundations are usually grid-like and built with the same ironware used to assemble the remaining components of the tower. The structure is then buried in the ground, and therefore, subjected to different corrosion processes, characteristic of different types of soil.

Tower foundations are susceptible to corrosion due to a myriad of contributing aspects, such as differential aeration, pH, soil moisture, and stray currents. The latter expedites corrosion in the foundations, particularly in high-voltage lines, such as the 525 kV lines. Burnett *et al.*[1] have theoretically demonstrated that, as a line is energized, a DC current associated with its electric field, along with an AC - 60 Hz component, *Ix* and *Iy*, respectively, are induced in the top cables. The AC-60 Hz current, *Iy*, consists of two components, *i.e.*, a *circulation component* (Icirc. comp.) and a *ground return component* (Ig.r.c.), which act together closing loops between adjacent towers, as is illustrated in figure 1 [1].

The objective of the present investigation was to assess the effect of stray currents on the corrosion process of tower foundations. This study has been carried out in the power lines of *Empresa Transmissora de Energia Elétrica do Sul do Brasil* S.A. (Southern Brazil Power Company), maintainer of 8,566 km of power lines connected mainly by metal towers of 69 kV, 138 kV, 230 kV, and 525 kV. Most of the towers have grid-like steel foundations manufactured from galvanized steel[2] depicting a protective layer 80 µm in average thickness. The distributor supplies energy to 11.1 % of the Brazilian consuming market including Southern and Midwestern states of *Rio Grande do Sul*, *Santa Catarina*, *Paraná*, and *Mato Grosso do Sul*.

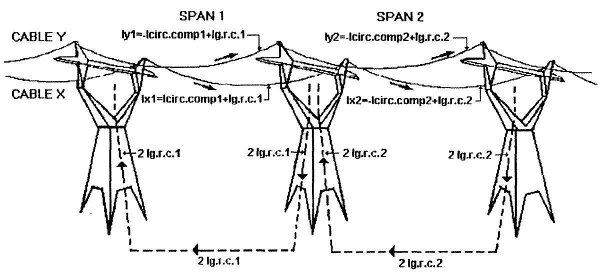


**Figure 1.** Illustrative representation of stray currents, according to Burnett *et al*[1].

*Figura 1. Representación ilustrativa de corrientes perdidas, según Burnett et al[1].*

Upon energizing the lines, electrical currents consisting of both an AC and a DC component are generated in the lightning rods. Monitoring those currents indicated that the direction of their DC component affected the magnitude of the corrosive process taking place at the foundations[1 and 6] of anodic towers. As a remedial action, the lightning-rods have been insulated from the power lines. This step also allowed a systematic study of the influence of DC-currents on the corrosion of high voltage towers.

## 2. EXPERIMENTAL PROCEDURE

The presence of stray currents in energized power was detected under normal operation conditions, *i.e.*, with the power line equipped with 3/8 EHS galvanized lightning rods, and energized to 525 kV[6]. The shape of both the potential and current signals measured at the base of the towers, upon disconnecting and connecting the rods to the structure, are shown in figure 2 [6].

The presence of AC and DC components originated from the electric and magnetic fields of

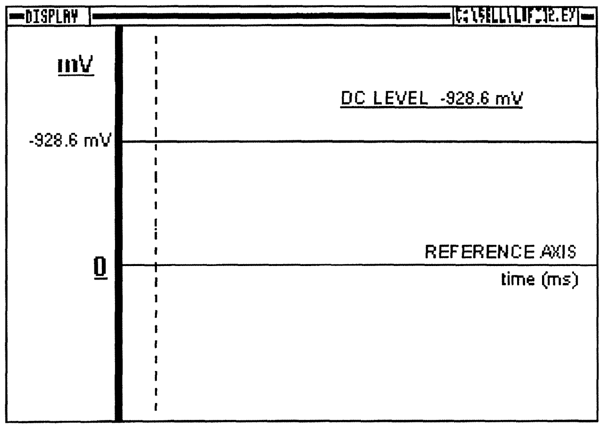


**Figure 2.** DC component measured with rods and tower disconnected.

*Figura 2. Componente de DC medido con cables y torre desconectados.*

the energized line[1 and 6] could be detected. They flowed from the lightning rod to the tower and acted as voltage and current sources. The levels of current and voltage obtained suggested extensive corrosion of the towers as a result of stray currents[7]. This assumption was later confirmed by visual inspection of the base of the respective towers. Potential tests were also carried out at the towers energized to 525 kV using a $Cu/CuSO_4$ reference electrode, as illustrated in figure 4. The potential was measured at pre-established distance intervals $x_1$ = 1.5 m for $V_1$ and $x_2$ = 3.0 m for $V_2$. To that end, an Engro MD 820a digital multimeter was used at a 2000 $mV_{cc}$ full scale along with a $Cu/CuSO_4$ reference electrode. The value of $x_1$ was chosen to account for voltage fluctuations caused by surface current density lines[5 and 8] near to and around tower foundations As such currents flow through a resistive volumetric conductor (ground), a surface voltage distribution turns out[5 and 8].

The grid-like configuration characteristic of the tower foundations reported herein was considered as the ground vertical pole, acting not only as a structural component, but also driving lightning discharges to the ground and accounting for "flash-over" currents originated along the lines and discharged by the lightning rods.

Considering that the foundation works as a pole, the resistance of the pole/ground system can be obtained either by the 3-point or by the Wenner method (four points). The result is expressed in terms of R (Ω). A pole/ground R (Ω) plot is illustrated in figure 5 [5 and 8]. R and d axes intersect at the pole/ground system (grid). From zero to $d_1$,

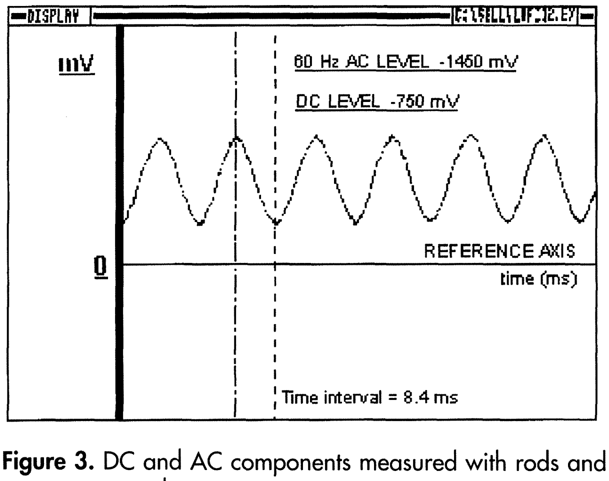


**Figure 3.** DC and AC components measured with rods and tower connected.

*Figura 3. Componentes DC y AC medidos con cables y torres desconectados.*

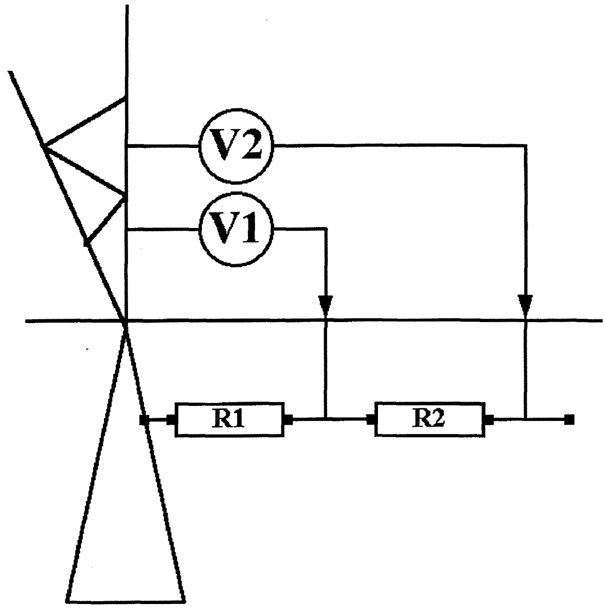


**Figure 4.** Schematic representation of potential measurements carried out at the base of the tower as a function of the distance using a $Cu/CuSO_4$ electrode.

*Figura 4. Representación esquemática de medidas potencial llevadas a cabo en la base de la torre como función de la distancia empleando electrodo de $Cu/CuSO_4$.*

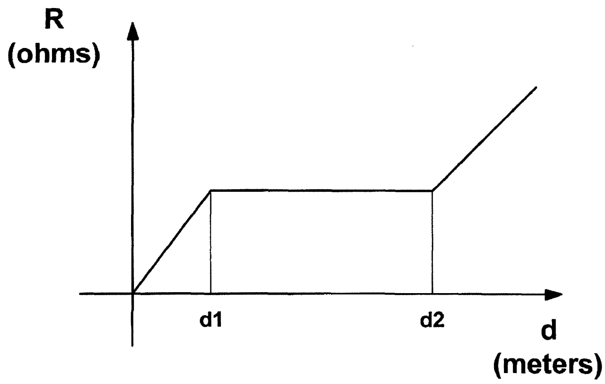


**Figure 5.** R(Ω) plot of pole/ground system.

*Figura 5. Gráfico R(Ω) del sistema torre/base.*

the plot is roughly linear. The distance $d_1$ corresponds to the value, in meters, of approximately twice the height of the pole (foundation), which is the minimum distance necessary to stabilize the resistance of the pole/ground system. Full stabilization occurs between 2 to 5 meters away from the pole. As the distances measured, 1.5 and 3.0 m, correspond to less than twice the height of the pole, measurements were taken in the linear region of the pole/ground system (Fig. 4).

## 3. RESULTS AND DISCUSSION

Table I summarizes the data obtained at the base of the 525 kV towers of ELETROSUL. The voltage is closely related to the flow of the stray current through the lightning rods of the line. Proof of that was obtained connecting the rods to the tower. They acted as current sources and intensified the corrosion process at the base of the towers. The values shown in table I were fitted to a straight line, as they fall in the linear region of the plot illustrated in figure 5. It can be seen that 82.40 % of the tests carried out at the base of the towers resulted in $\Delta V_1 < \Delta V_2$ . Plots having a positive slope (a=tan $\alpha$) were associated with anodic towers. The corresponding foundations were visually inspected in an attempt to assess the situation of the corrosion process. As it can be seen from figure 6 (a) and (b), the foundations showed evidence of extensive corrosion. The influence of the stray current flowing in those foundations was verified measuring the voltage at the base of anodic towers in advanced stage of corrosive degradation (Fig.6)[7].

Conversely, plots with negative slope (-a=tan $\alpha$) suggested a cathodic process-taking place at the foundations. Such towers were also visually inspected, but no signs of corrosion could be detected. Figure 7 (a) and (b) show an example of a well-preserved structure corresponding to a cathodic tower.

**Table I.** Variation of ΔV1 and ΔV2 along Eletrosul power lines

*Tabla I. Variación de ΔV1 y ΔV2 a lo largo de líneas de energía de la Eletrosul*

| Lines of Eletrosul system (kV) | Nº of towers $\Delta V_1 < \Delta V_2$ | % | Nº of towers $\Delta V_1 > \Delta V_2$ | % | Total Nº of towers measured |
|---|---|---|---|---|---|
| 525 | 1014 | 80.1 | 251 | 19.8 | 1265 |
| 230 | 729 | 80.4 | 177 | 19.5 | 906 |
| TOTAL | 1743 | 80.2 | 428 | 19.7 | 2171 |

## 4. CONCLUSIONS

Significant induced currents consisting of AC and DC components flow through lightning rods of extra-high voltage cables — 525 kV. As the loop between adjacent spans is closed, the currents flow between towers in an electrochemical process. The counter-part of such currents is the stray current, which speeds up the corrosive process of anodically polarized towers. The effect of the stray current can be significantly reduced insulating the lightning-rod cables. Studies are still under way to verify the effect of the stray current on the resting electrode potential in an attempt to determine the conditions that lead to either anodic or cathodic processes at the tower foundation.

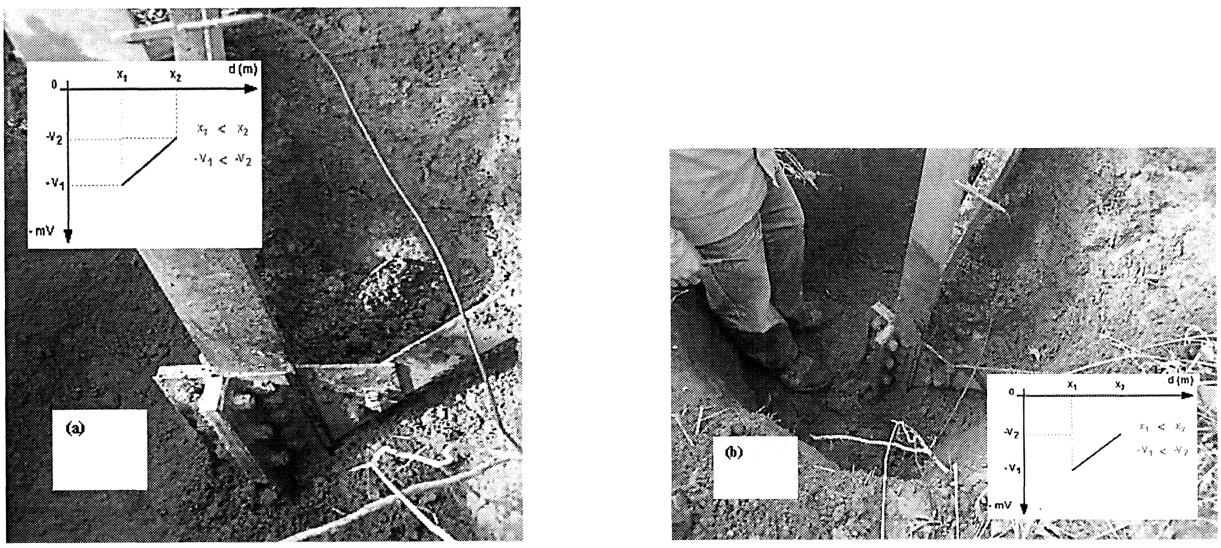


**Figure 6.** Images of anodically polarized foundation.

*Figura 6. Imágenes de una base polarizada anódicamente.*

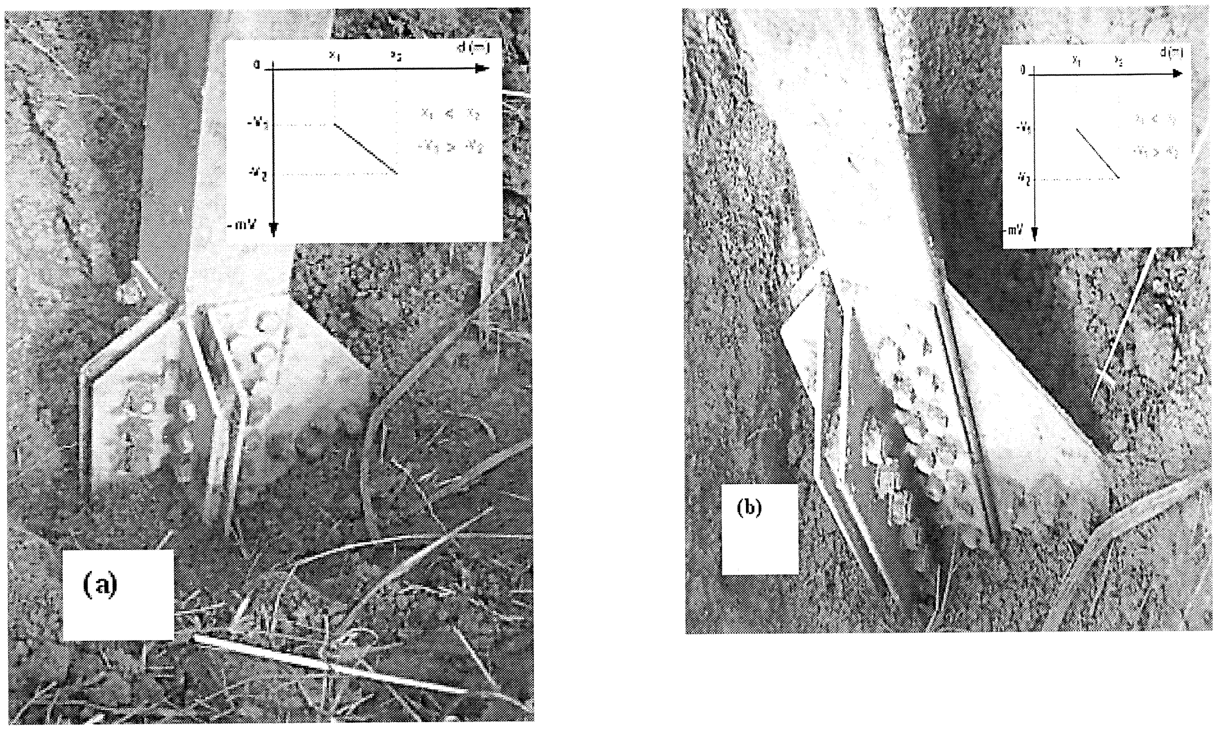


**Figure 7.** Images of a cathodically polarized foundation.

*Figura 7. Imágenes de una base polarizada catódicamente.*

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