Effect of Shield Wires on GICs

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Abstract

The influence of shield wires on Geomagnetically Induced Currents (GICs) in power systems is considered. For the most simple power network, with one single transmission line and one shield wire connecting two substations, we derive the expressions for the voltage source and the resistance of the Thévenin equivalent circuits that, in parallel with the substations grounding resistances, produce the same effects on GICs as the full circuit. Our model extends results from previous studies that considered the effect of shield wires resistances by also including the induced geoelectric field.

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***Index Terms*—GICs, Shield Wires, Induced Geoelectric Field**

I. Introduction

When energized charged particles from the Sun enter the magnetosphere, variations in the Earth's magnetic field induce a geoelectric field in the Earth. Along grounded conductive structures as power lines, this field drives electric currents called geomagnetically induced currents (GICs). GICs computation is gaining importance due to major consequences they may cause as, e.g., blackouts.

Shield wires are conducting lines strung above power lines to protect them from lightning strikes. They can be grounded at the supporting pylons and at substations, thus representing possible paths for GIC currents. A comprehensive study using the nodal analysis method was carried out by [1], where the network model integrated both a single transmission line and the nonlinear magnetization of transformer cores. It was noted that different values for the shield wire resistances would lead to significant differences in the GIC intensity through transformer windings and, for the studied cases, the effect was a decrease in GICs. Recently, [2] have revisited this problem. Neglecting induced voltage sources along shield wires, it was concluded that the shield wire circuit could be represented by an equivalent circuit consisting of a resistor connected in parallel to each substation grounding resistor. The expression for those resistances was derived and shown to depend on the characteristics of tower footing grounding and shield wires. By reducing the equivalent ground resistances at substations, the shield wire effect would increase GICs. Different conclusions drawn in previous studies, as explained above, ask for further studies on shield wires effect over GICs.

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II. Shield Wire in a single Power Line Model

A simple circuit model consisting of only two substations, A and B, with transformer winding resistances R_{TA} and R_{TB} and grounding resistances R_{SA} and R_{SB}, is shown in Figure 1. It considers a single transmission line with resistance R_L and total induced *emf* V_L, and a single shield wire, between substations. The shield wire is grounded at each tower i, through resistance R_{Gi}, and at both substations. Each segment i of shield wire has resistance R_{Wi} and induced *emf* V_i.

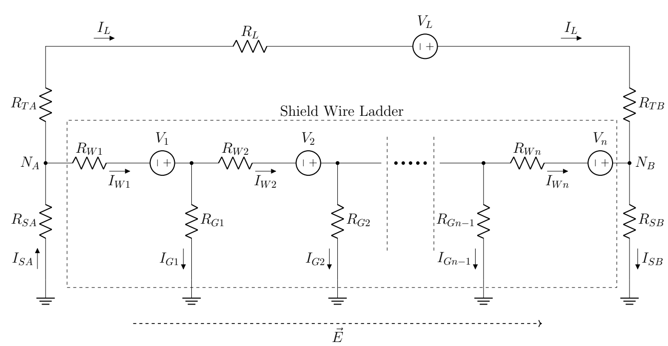

Fig. 1: Elementary circuit model to analyse the effect of shield wires on GICs through the transformers (from [2]).

A. Recursive Equations

In Figure 1, the circuit connected to R_{SA} and inside a box is a chain-like series of n similar loops (each one called a ladder step). In order to obtain the circuit equivalent to the ladder as seen from A, one first considers the farthest step of the ladder circuit on the right, the one which includes R_{SB}. Thévenin's theorem is then applied to get an equivalent circuit

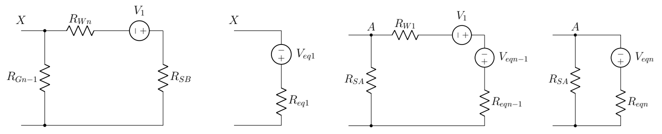

Fig. 2: First (left) and last (right) steps of the ladder circuit, with corresponding Thévenin equivalents.

as shown in Figure 2. Expressions for the equivalent resistance and voltage are given by

$$R_{eq1} = (R_{Wn} + R_{SB}) \frac{R_{G(n-1)}}{R_{G(n-1)} + R_{Wn} + R_{SB}}$$
$$V_{eq1} = V_n \frac{R_{G(n-1)}}{R_{G(n-1)} + R_{Wn} + R_{SB}} \tag{1}$$

The recursive analysis proceeds by adding the last but one ladder step to that first equivalent circuit (Figure 2, left) and using again Thévenin's theorem. To compute values at a given ladder step i requires knowledge of values computed in step $i-1$. The general recursive equations are the following, from $i = 2$ to $i = n-1$:

$$R_{eqi} = \frac{(R_{W(n-i+1)} + R_{eq(i-1)})R_{G(n-i)}}{R_{G(n-i)} + R_{W(n-i+1)} + R_{eq(i-1)}}$$
$$V_{eqi} = \frac{(V_{n-i+1} + V_{eq(i-1)})R_{G(n-i)}}{R_{G(n-i)} + R_{W(n-i+1)} + R_{eq(i-1)}} \tag{2}$$

The expressions for the resistance and voltage source of the Thévenin equivalent to add in parallel to R_{SA} are:

$$R_{eqA} = R_{eqn} = R_{eq(n-1)} + R_{W1}$$
$$V_{eqA} = V_{eqn} = V_{eq(n-1)} + V_1 \tag{3}$$

The equations above take a simpler form if all R_{Wi}, R_{Gi} and V_i values can be made equal, in which case they reduce to only three different parameters R_W, R_G and V. The Thévenin equivalent resistance and voltage source for an increasing number i of ladder steps are plotted in Figure 3. It can be seen that R_{eqi}, as well as V_{eqi}, approach an asymptotic value for a long enough power line.

B. Asymptotic Expressions

In the asymptotic regime, $R_{eq(i-1)} \sim R_{eqi}$ and $V_{eq(i-1)} \sim V_{eqi}$. The number of steps to reach the resistance asymptote (Figure 3, top) depends on R_W and R_G: the smaller (R_W/R_G), the slower the convergence. In the same way, V_{eqi} approaches a stable value within $\sim$ 30 ladder steps (Figure 3, bottom), and the smaller (V/R_G) is the slower the convergence. Asymptotic expressions for Eq. (3) yield:

$$R_{eqA} = \frac{R_W}{2} + \sqrt{R_W \cdot R_G}$$
$$V_{eqA} = V \left[\frac{R_G}{\frac{R_W}{2} + \sqrt{R_W \cdot R_G}} + 1 \right] \tag{4}$$

A very practical outcome of the asymptotic behaviour of the recursive sequences is that expressions (4) can be used to characterize the Thévenin equivalent to the shield wire system, as long as the line lengths are large enough and the shield wire parameters R_G and R_W, as well as the induced voltage source V, are homogeneous along the line. With this simple circuit, the heavy computational task of modelling the shield wire system explicitly may be bypassed.

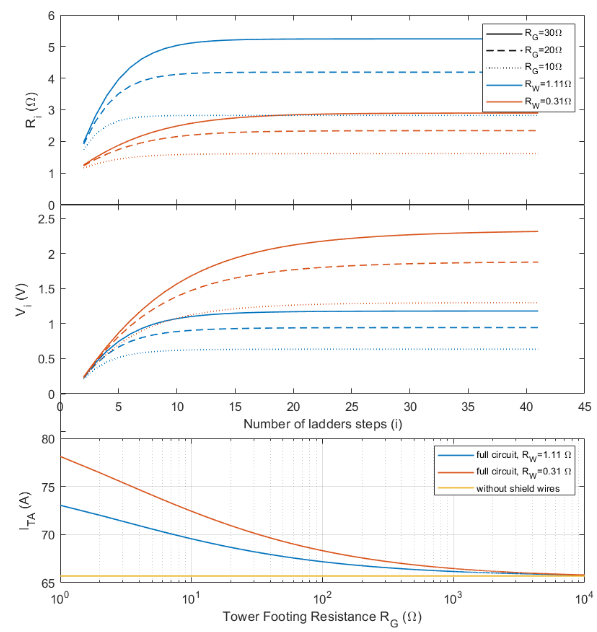

Fig. 3: R_{eqi} (top) and V_{eqi} (center), from Eq. (2), for increasing number of ladder steps and different values of R_W and R_G. I_{TA} (bottom) represents GICs through the transformer (V_L=473V, R_L=4.2Ω, R_T=0.5Ω, R_S=1Ω, V=0.25V).

III. Conclusion

Recursive expressions were obtained for the resistance and voltage source of the Thévenin equivalent circuits that, once connected in parallel to each substation grounding resistance, have the same effect as the full shield wire circuit on the current crossing the transformer windings. Asymptotic expressions were also derived that allow a significant simplification of the circuit equations. Higher values of R_W lead to higher values for the shield wires equivalent resistance and a more quick convergence to asymptotic values. Higher values of R_W also favour lower values for the shield wires equivalent induced *emfs*, but the two equivalent *emf* at the end substations tend to balance. In the end, shield wires contribute to increase the GICs through the transformers in a single line model, especially for lower R_W values (Figure 3).

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