The Calculation of Short Circuit Currents in Overhead Ground Wires Using the EMTP/ATP

Marco Polo Pereira **Paulo Cesar Vaz Esmeraldo**

Furnas Centrais Elétricas S.A.
Transmission Planning Department
Rua Real Grandeza, 219, Sala 1607
CEP 22283-900 - Rio de Janeiro, Brazil
mpolo@furnas.gov.br
esmerald@furnas.gov.br

Abstract – The overhead ground wires, besides improving the transmission line performance against lightning, also can be used for the transmission of signals or, more recently, for the transmission of data, with the installation of optical fiber ground wires (OPGW). The short-circuit current that circulates during the occurrence of a phase-to-ground fault near the substation is one of the most important parameters for the specification of the OPGW. For each installation it is necessary to determine the type, diameter and length of each one of the ground wires necessary to withstand the corresponding short-circuit currents.

Keywords: Short circuit currents, OPGW, ground wires, EMTP/ ATP, Alternative Transients Program.

I. INTRODUCTION

The purpose of this article is to present the practical methodology and the EMTP/ATP modeling techniques used in a prospective study regarding the installation of OPGW in 345 and 500 kV transmission lines in Brazil. The usual procedure is to substitute one of the existing grounding wires by an OPGW. The theoretical background was not investigated because the EMTP/ATP has all the models needed for the full determination of all the currents that are involved in the OPGW specification. The basic approach is to show which are the specific aspects and which are the details that have to be take in account when performing such type of simulation.

II. GENERAL REMARKS

The currents caused by phase-to-ground faults in the transmission return through the ground and the ground wires. The fault can occur in any place along the transmission line and the short-circuit current is higher near the substations. As the path for the current to reach the ground passes through the grounding system of the structure where the short circuit occurred, the tower-footing resistance is a component to be included in the modeling of the circuit. The part of the current that returns through the ground wires depends on its impedances, and, therefore, on the place where the fault occurred and on the characteristics of each one of the ground wires.

There are cases where ground wires of higher capacity have to be used for a certain length near the substations because the fault currents are higher near the substations. Usually this length is such that the amount of impedance in the cables is enough to reduce the fault current to a level that is below their current carrying capacity.

The behavior of the fault current along the transmission line is indicated in the Figure 1.

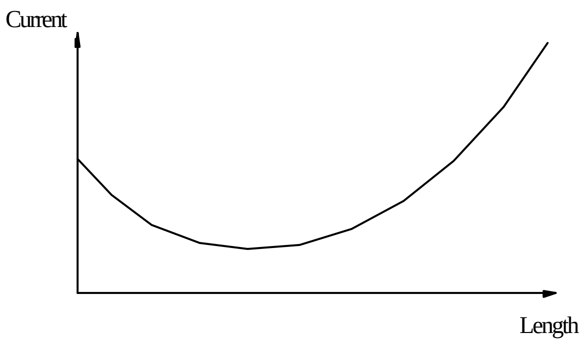

Figure 1 – Variation of the fault current along the transmission line

When new cables (like the OPGW) are installed in substitution to one of the existing ground wires, the division of the current between the two different types of cables is a function of the impedances of the new set of cables. It is possible that different lengths and types of ground wires have to be used near the substations, mainly for the places in the electric system where high short-circuit currents can circulate in the grounding cables.

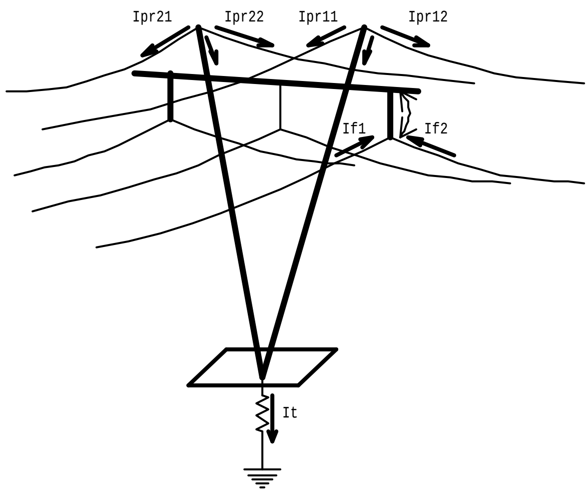

Figure 2 – Circulation of fault currents in the cables and in the ground

The circulation of the fault currents in the conductor cables, ground wires and in the grounding system of the structures can be seen in the Figure 2.

III – THE CALCULATION OF FAULT CURRENTS

The process for finding the appropriate type of cable and its length is interactive, beginning with the calculation of the parameters of the transmission line for each specific configuration of ground wires and conductor cables. After the parameters are calculated the simulation of faults along the transmission line must de done in order to compare the calculated values with the current carrying capacity of the ground wires.

The configuration of the circuit is shown in Figure 3. The modeling of the transmission line consists basically of three sections. Just a single section can model the central part of the transmission line, but near the two substations it is necessary to detail each span. This is done because this is the region where the higher stresses can occur in the ground wires. Due to these higher stresses it is possible that different type of cables have to be used in this region.

The main purpose of the simulations is the determination of the short circuit currents, being, therefore, a problem in the industrial frequency range. The models of the components have to be established for that purpose. The transmission line has to be detailed as shown in the Figure 3 and have to be modeled by a component that allows the representation of all cables. The short circuit equivalent impedances at the two substations in the ends of the transmission line must be represented.

It is recommended that all simulations be done with a program that allows the complete representation of all the involved elements, basically the ground wires, the phase conductor cables, the short circuit equivalent impedances, the transfer impedance between the two substations and the sources behind the short-circuit equivalents.

The EMTP/ATP allows the representation of all the components indicated above for any configuration with almost any quantity of elements.

Together with the EMTP/ATP (being part of the same computational package) there are the LINE CONSTANTS routine (for the calculation of transmission line parameters), the LCC (which allows the creation of the input data file for LINE CONSTANTS) and the ATPDRAW (an auxiliary program, mainly for the creation of the input data files for the EMTP/ATP). This set of programs is fully adequate for the modeling of all the involved components and its use is recommended.

The determination of the short-circuit currents in the ground wires is very laborious because it involves a great amount of data manipulation and a lot of steps until an acceptable solution is found. This is mainly caused because the EMTP/ATP is a program that was developed basically for the calculation of transients and in this case it is being used just for finding results in the industrial frequency range.

The PI-sections used in the modeling of the transmission line, as shown in the Figure 3, have to be calculated for each one of the configurations regarding each possible set of cables (types and lengths) that could be considered as for the solution of the problem.

The scheme indicated in Figure 3 is mounted as a circuit in the EMTP/ATP and simulations of faults (like the one indicated on tower 3) along the transmission line are carried out. The fault is represented by a connection of low impedance between the phase and the tower in the point of interest. The short circuit currents in each one of the ground wires are verified and compared with the current carrying capacities of the cables.

When the current carrying capacity of the cable is exceeded a new configuration must be simulated,

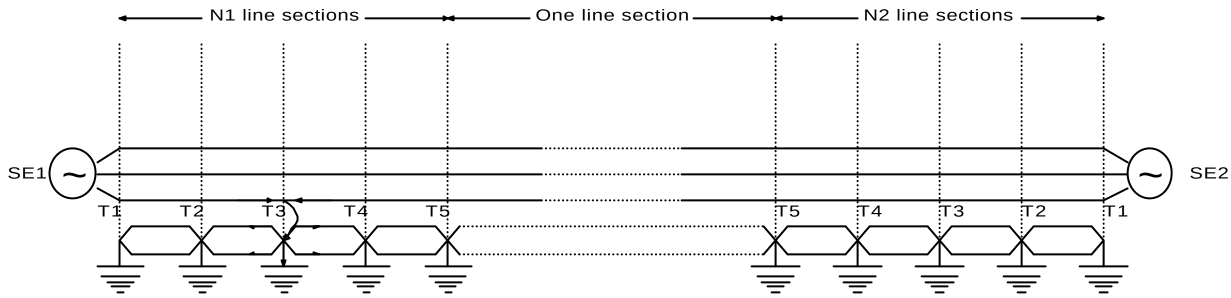

Figure 3 – Diagram showing the modeling of the transmission line

considering a new type of OPGW or conventional ground wire. In some situations it is necessary to modify the type and/or the extension of the existing ground wires to better allow the division of the current between the conventional ground wire and the OPGW.

It is necessary to verify the current distribution between the cables in each point of transition for a new configuration of cables (when different types of cables have to be used). In these points, usually an OPGW of lesser capacity, in parallel with a conventional ground wire of high impedance, takes most of the current, being an important point for the verifying the correct sizing of the OPGW cable.

Therefore, the process is interactive and the solution depends on a great amount of simulations and verifications so that optimized configurations can be obtained for the types and lengths of ground wires.

The OPGW data have to be obtained directly from the manufacturers. Usually this type of cable is still in the developing phase and they have been submitted also to other type of tests, like the tests for lightning discharges currents of low intensity which flow just after the main stroke ceases.

IV. MODELING IN THE EMTP/ATP

The transmission line, which is the main element in the simulation, is represented by a sequence of PI-models of the EMTP/ATP. The length of each section is a function of the length of the average span of the transmission line under study, usually in the range 400 to 450 meters.

The central part of the transmission line, which normally does not need to be detailed, can be represented by just one PI-section, independently of the length.

The calculation of the parameters of each PI-section is obtained by using the "Line Constants" program, being the input data file prepared with the LCC program. It should be used the option for the creation of the transmission line model (.pch file), as well as the " reference branch" option in order to facilitate the data assembly of the corresponding input data file for the EMTP/ATP simulations.

For the present type of modeling that was used for the simulations it was found that it was necessary to use the ATP for WindowsNT version because of the great amount of components. The current EMTP/ATP version (ATP Salford) doesn't have enough capacity for the modeling in question.

The sources were represented by type 14 (AC sources at the fundamental frequency, 60 Hz for the case) in series with the short-circuit equivalent impedances seen at the two ends of the transmission line.

Resistances of very small values represent the fault. In order to facilitate the reading of the currents in the cables, resistances of very small values were added at the cable connections at each tower. Using this procedure it is possible to use the option of the EMTP/ATP that allows the determination of the maximum values occurred in the simulation. By using this option it is possible to read the data directly from the transient part of the solution and not from the steady state solution. The sources can be conveniently adjusted for obtaining RMS values.

A schematic input data file for the EMTP/ATP is shown in the Attachment I. The full file has more than 1400 lines of instructions and it would be impossible to include it in its complete form.

V. ADDITIONAL REMARKS

The correct specification of the ground wires depends on the correct determination of the fault currents that circulate in the cables during the fault to ground. These faults are highly affected by the physical and electric parameters of the components involved in the simulation. Many aspects are of concern for this type of simulation.

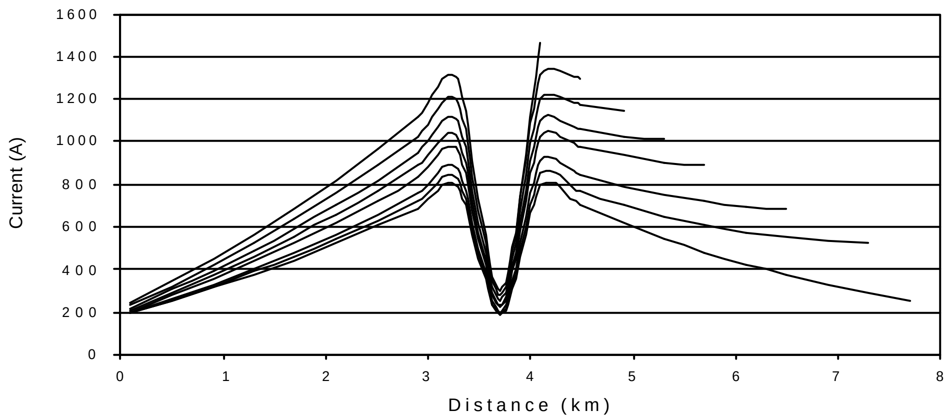

Figure 4 - Currents in the tower-footing resistances

The distribution of the currents in the cables is directly dependent of the of the short circuit equivalents and of the voltage of the source. The corresponding impedances of the short circuit equivalents must be calculated considering the long-run expansion of the network. The voltage of the source must be the maximum steady-state operating voltage of the system.

The tower-footing resistances affect the flow of the current in the cables. The actual distribution of tower-footing resistances for the worse conditions should be used, but they aren't always available.

The option would be, then, to use average values, being important to use some conservative combination of values.

In the point where the fault is applied it can be used a high value, as well as in the adjacent towers for the side of the transmission line where the fault current decreases. In the other direction, lower average values should be used. With this combination of values for the tower-footing resistances the greatest part of the currents in the cables is forced to return for the nearest substation, maximizing the current that circulates in the ground wires.

The Figure 4 shows the currents in the tower-footing resistances, in function of the representation of the resistances in the adjacent towers towards the middle of the transmission line. In this in case there is a higher resistance (100 ohms) in the point where the fault occurs and lower values (20 ohms) in the other towers. The fault is always simulated in a tower that is located 3.7 km from the nearest substation. For the case there is an initial span equal to 100 m and all the others have 400 m. Each curve exists until a certain length because from that point no grounding resistances were included in the simulation.

It can be seen a significant variation in the currents measured in the tower-footing resistances, demonstrating clearly that it is necessary to include the resistances of the adjacent towers in order to correctly determine the circulating currents in the ground wires.

The currents in the ground wires are shown in the Figure 5, in function of the representation of the tower-footing resistances in the adjacent towers, for the side towards the central part of the transmission line and for the same case shown in the previous Figure 4.

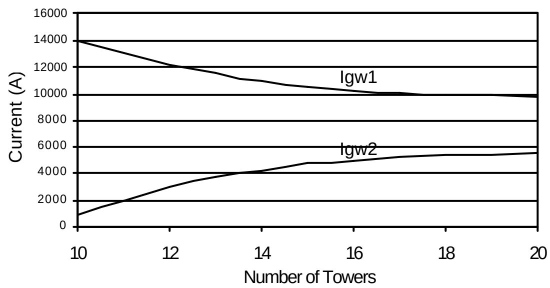

Figure 5 – Currents in the ground wires

It is clearly observed that special care must be given to include a certain number (10 as in this case) of adjacent towers towards the other end of the transmission line. The difference between the two extreme cases is more than 40 % in the value of the current in the ground wire.

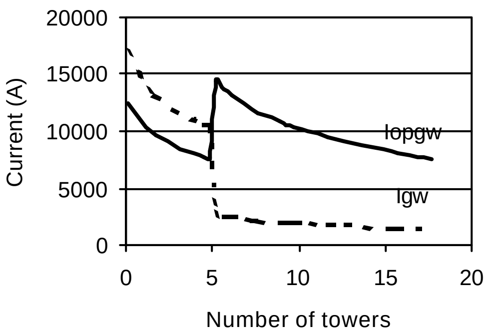

Figure 6 - Current variation in the transition point

In the Figure 6 it is shown the variation in the current at the point of transition from a type of ground wire to another of smaller diameter.

VI. CONCLUSIONS

A) The correct specification of a ground wire depends basically on the short circuit currents that circulate in the cables during the occurrence of phase-to-ground faults along the transmission line. The circulating current is greater for faults in the neighborhoods of the substations.

B) Considering the complexity of the calculations, it is recommended that the simulations are carried out with a program such the EMTP/ATP, which allows the complete representation of all the involved elements.

C) The installation of OPGW increases the complexity of the simulations because it introduces a cable with different characteristics when compared to the traditional ones. In some situations it is necessary to modify the diameter and/or the extension of the existing cables to better divide the current between the conventional cable and the OPGW.

D) The models available in the ATP/EMTP are fully satisfactory for the determination of the short circuit currents, but the process is interactive and very laborious. Special care must be taken to establish a systematic process for assembling the cases.

E) The modeling of the configuration in analysis must be carried out tower by tower in the neighborhoods of the substations, being necessary to represent a reasonable quantity of towers after the point of application of the fault towards the central part of the transmission line.

F) The process, although technically simple, is very laborious and time consuming, being necessary to establish a systematic way for obtaining the values of the currents in the ground wires.

G) The points of transition for the configurations with different type of cables must be verified very carefully, in view of the redistribution of the currents that occurs in these points.

H) The technical data about the characteristics of the OPGW cables, as well as on its short-time current carrying capacities, are of fundamental importance for the specification of the ground wires.

VII. REFERENCES

[1] H. W. Dommel, EMTP Theory Book, BPA, Portland, August 1986.

[2] Can/Am Users Group, ATP Rule Book.

[3] H. K. Hoidalen, L. Prikler and J.L. Hall, “ ATPDraw-Graphical preprocessor to ATP, Windows version” , International Conference on Power Systems Transients, June 20-24, 1999, Budapest.

Attachment I – Partial Input data file for EMTP/ATP

```
BEGIN NEW DATA CASE
C Generated By ATPDRAW  December, Wednesday 15, 1999
C Miscellaneous Data Card ....
C  dT  >< Tmax >< Xopt >< Copt >
   .0001    .100     60.     60.
     500       1       0       0       1       0       0       0       0
/BRANCH
C EQUIVALENT IMPEDANCE FOR SUBSTATION 1
51   F1A  SE1A                        23.3
52   F1B  SE1B                        21.8
53   F1C  SE1C
C EQUIVALENT IMPEDANCE FOR SUBSTATION 2
51   F2A  SE2A                        10.0
52   F2B  SE2B                        11.5
53   F2C  SE2C
C TRANSFER IMPEDANCE BETWEEN THE TWO SUBSTATIONS
51  SE1A  SE2A                       1226.
52  SE1B  SE2B                        81.2
53  SE1C  SE2C
C GROUNDING RESISTANCE AT THE SUBSTATIONS
    TSE1                     0.5
    TSE2                     0.5
C PHASE-TO-GROUND FAULT SIMULATION
     XT1  XA1A            .10E-3                                              1
C CURRENT MEASUREMENT IN THE GROUND WIRES
C TOWER X1
    XAP1   XT1            .10E-3
    XAG1   XT1            .10E-3
     XT1  XBP1            .10E-3
     XT1  XBG1            .10E-3
```

```
      -------------------------------------------------
      THE SAME MEASURING STRUTURE IS USED FOR ALL TOWERS
      -------------------------------------------------------

C TOWER-FOOTING RESISTANCES
     XT1                   20.0

     ---------------------------------------------
     ALL TOWER-FOOTING RESISTANCES ARE REPRESENTED
     ---------------------------------------------------

C BEGINING OF THE TRANSMISSION LINE MODEL
C FIRST SECTION NEAR THE SUBSTATION 1 (100 METERS) [NOT SHOWN IN THIS FILE]
C SECOND SECTION NEAR THE SUBSTATION 1 (400 METERS)
$VINTAGE, 1
 1  XA1A  XA2A             3.69878135E-02  3.23176537E-01  4.11954918E-03
 2  XA1B  XA2B             2.34647634E-02  1.80294747E-01 -7.09441581E-04
                           3.69822693E-02  3.23175893E-01  4.24858830E-03
 3  XA1C  XA2C             2.34633533E-02  1.59440133E-01 -2.11589948E-04
                           2.34647634E-02  1.80294747E-01 -7.07510143E-04
                           3.69878135E-02  3.23176537E-01  4.12299397E-03
 4  XBP1  XAP2             2.33933784E-02  1.74517823E-01 -4.44034401E-04
                           2.33893542E-02  1.71413931E-01 -3.48437878E-04
                           2.33898561E-02  1.57971059E-01 -1.77417160E-04
                           1.69932906E+00  4.14713249E-01  2.57179085E-03
 5  XBG1  XAG2             2.33898561E-02  1.57971059E-01 -1.89551261E-04
                           2.33893542E-02  1.71413931E-01 -3.69146264E-04
                           2.33933784E-02  1.74517823E-01 -4.68834455E-04
                           2.33160474E-02  1.68739983E-01 -2.86810787E-04
                           2.39343047E-01  3.98516962E-01  2.70759196E-03
$VINTAGE, 0
C    1500.      60.        1              1      .4 00000       44
C SECOND SECTION NEAR THE SUBSTATION 1 (400 M) [USING REFERENCE BRANCH OPTION]
 1  XA2A  XA3A  XA1A  XA2A
 2  XA2B  XA3B
 3  XA2C  XA3C
 4  XBP2  XAP3
 5  XBG2  XAG3

     ---------------------------------------------------------------------
     N1 PI-SECTIONS (400 M EACH) FOR REPRESENTING THE TL NEAR SUBSTATION 1
     ---------------------------------------------------------------------

C CENTRAL SECTION OF THE TRANSMISSION LINE (45.8 KM) [NOT SHOWN IN THIS FILE]

     ----------------------------------------------------------------------
     BEGININIG OF THE PI-SECTIONS FOR REPRESENTING THE TL NEAR SUBSTATION 2
     ----------------------------------------------------------------------
/SWITCH
C < n 1>< n 2>< Tclose ><Top/Tde ><   Ie   ><Vf/CLOP ><  type  >
/SOURCE
C < n 1><><YAmpl.  >< Freq.  ><Phase/T0><  XA1   ><   T1   >< TSTART >< TSTOP  >
C SOURCE BEHIND THE EQUIVALENT IMPEDANCE AT SUBSTATION 1
14   F1A 0   199200.       60.                                      -1.        1.
14   F1B 0   199200.       60.     -120.                            -1.        1.
14   F1C 0   199200.       60.      120.                            -1.        1.
C SOURCE BEHIND THE EQUIVALENT IMPEDANCE AT SUBSTATION 2
14   F2A 0   199200.       60.                                      -1.        1.
14   F2B 0   199200.       60.     -120.                            -1.        1.
14   F2C 0   199200.       60.      120.                            -1.        1.
BLANK BRANCH
BLANK SWITCH
BLANK SOURCE
BLANK OUTPUT
BLANK PLOT
BEGIN NEW DATA CASE
BLANK
```