Methodologies to determine the fault current through an OPGW (OPtical Ground Wire)

Héctor R. Disenfeld

Abstract-- To specify the OPGW (Optical Ground Wire) in a transmission line, it is necessary to know the maximum thermal stress it will have to resist.

To do it, it is necessary to determine the current that will pass through the OPGW, in the eventuality of a single phase to ground fault.

The ATP calculation program is used to obtain the single phase to ground fault current, but it does not discriminate the current that circulates through the OPGW and the ground wires.

One of the methodologies used to solve this problem is the Sequence Parameters Method. This method is based on a series of estimations of positive and homopolar sequences developed under the assumption of presence and absence of the conductors (OPGW and ground wires). From a mathematical point of view, this method solves the problem.

The other methodology followed to solve the above-mentioned situation is the Short Line Simulation Method. It consists of the simulation of a span length line, (where the OPGW and ground wires are simulated as additional conductors, not grounded ones) to which a single phase to ground fault is applied and the distribution of currents is analyzed.

Finally, conclusions are given with a comparison between both methods, and a validation of the obtained results.

Keywords: OPGW, Fault Current, Current Distribution, Thermal Requesting.

I. Nomenclature

I_G, Z_G: "The Ground" Current and "The Ground" Impedance

I_{GW}, Z_{GW}: Ground Wire Current and Ground Wire Impedance

I_{OPGW}, Z_{OPGW}: OPGW Current and OPGW Impedance

II. Introduction

A new transmission line of 1300 km in 500 kV between E.T. Piedra del Aguila, located in the south west of the country and Abasto, Buenos Aires province, was built with one OPGW as a ground wire. Afterwards, it was necessary to extend this communication system up to Ezeiza Substation located 60 km away.

To carry out this project, the preexisting high transmission line, which joins Abasto and Ezeiza, had to be used.

This line is placed in an area where largest short circuit currents are registered in Argentina.

In this case, and due to mechanical related reasons, it was decided not to replace one of the existing ground wires, but to locate the suspensions of new OPGW below the ground wires and over the phase conductors.

Fig. 1 shows the diagram of the tower and location of the OPGW.

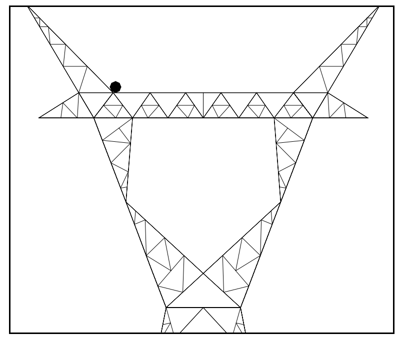

Fig. 1. Diagram of the tower and location of the OPGW.

The information concerning the position of the OPGW, both ground wires and conductors with dimensions, conformation and electrical data of the OPGW, as well as the data entry to the ATP Program, subject to this geometry and its conductors ground wires and OPGW dimensions and characteristics, can be found in Figures 8, 9 and 10 of the Appendix

To determine the thermal standard of the OPGW (Optical Ground Wire) it is necessary to know the magnitude of current that will pass through the OPGW in case of single phase to ground fault.

The ATP Program can calculate the single phase to ground fault current, but it does not discriminate the currents that circulate through the OPGW and the ground wires. Two methods are hereby analyzed highlighting those parts of the single phase to ground fault current that flow through them.

III. Sequence Parameters Method

Usually, programs give us the information on the single phase to ground fault current; it has 3 ways of return.

a) OPGW
b) both ground wires
c) "the ground"

For the case c, i.e. "the ground", the tower-footing resistance is present, therefore in the proximity of the fault, we can say that almost the total of the current will flow through the OPGW and the both ground wires. Then, as we get further away from the point where the fault occurred, the amount of current by "the ground" will increase.

The ATP can determine the total fault current, but it does not specify how this current is distributed between the OPGW

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and both ground wires.

To solve this, we use the information provided by the LINE CONSTANTS supporting routine in ATP

From it, positive and homopolar sequence parameters are obtained (Z1 and Z0 respectively).

Based on these parameters, any line can be represented with the circuital scheme shown in Fig 2.

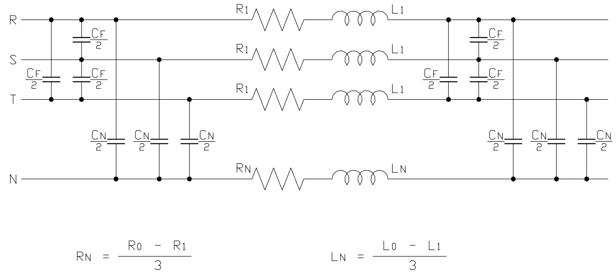

Fig. 2. Circuital scheme for transmission line - Sequence Parameter Method

This diagram shows a three-phase transmission line with Z_1 impedance in each phase and with ground return impedance

$$Z_N = \frac{Z_0 - Z_1}{3}$$

The failure current will flow through the ground return impedance Z_N.

For the case under analysis, the Z_N value obtained through LINE CONSTANTS supporting routine is the ground return impedance, including the OPGW, both ground wires and "the ground".

That means that a Z_N has three elements in parallel, as shown in Fig 3.

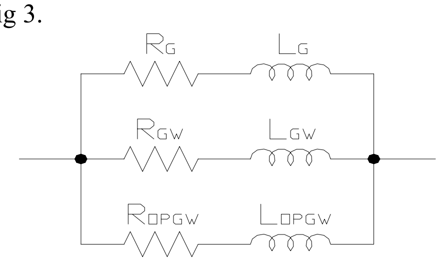

Fig. 3. Ground return including the OPGW, both ground wires and "the ground".

A. To rule out "the ground" return current, due to tower-footing resistance.

To determine Z_N values of the OPGW and both ground wires components we proceed this way.

1) The sequence parameters of the line are determined, taking into account neither the presence of both ground wires nor the OPGW, thus obtaining the Z_N value, given by "the ground".

2) The same process is repeated for the line including both ground wires but not the OPGW, and obtaining another Z_N value that is the parallel of "the ground" with both ground wires.

3) The sequence parameters of the line are determined, this time considering the OPGW but not both ground wires, and obtaining a third Z_N value, which is the parallel of "the ground" with OPGW.

The Z_N value of "the ground" will be named Z_G, the Z_N value of both ground wires, Z_{GW} and the Z_N value of the OPGW, Z_{OPGW}.

Therefore: from 1) $Z_{N1} = Z_G$, from 2) $Z_{N2} = Z_G \,//\, Z_{GW}$, and from 3) $Z_{N3} = Z_G \,//\, Z_{OPGW}$.

So if we have $\boxed{Z_A \,//\, Z_B = Z_P}$

will be $\boxed{Z_B = (Z_A * Z_P) / (Z_A - Z_P)}$

Based on this, and having the sequence parameter calculus for the configurations mentioned in 1), 2) and 3), we can determine the values Z_G, Z_{GW} and Z_{OPGW}.

Proceeding in this way, the following sequence parameters for the different configurations (from LINE CONSTANTS supporting routine) are obtained.

<u>1) Case with neither ground wires nor the OPGW</u>

Sequence	Resistance ohm/km	Reactance ohm/km	Susceptance mho/km
Zero :	1.66561E-01	1.04319E+00	2.62626E-06
Positive:	2.39263E-02	2.82197E-01	4.09277E-06

$Z_{N1} = Z_G = R_{N1} + X_{N1} = \underline{(0{,}0475 + j\,0{,}2537)\ \Omega/km}$

<u>2) Case with both ground wires and without the OPGW</u>

Sequence	Resistance ohm/km	Reactance ohm/km	Susceptance mho/km
Zero :	2.82762E-01	9.29305E-01	2.89746E-06
Positive:	2.46797E-02	2.82012E-01	4.12479E-06

$Z_{N2} = Z_G \,//\, Z_{GW} = R_{N2} + X_{N2} = (0{,}0860 + j\,0{,}2158)\ \Omega/km$

Once we know the Z_G value of 1) and the

$Z_G \,//Z_{GW}$ value of 2), mathematically we get Z_{GW} value.

$$Z_{GW} = (Z_G * (Z_G \,//\, Z_{GW})) / (Z_G - (Z_G \,//\, Z_{GW}))$$
$$= \underline{1{,}0848\ \Omega/km + j\,0{,}2347\ \Omega/km}$$

<u>3) The OPGW and no both ground wires</u>

Sequence	Resistance ohm/km	Reactance ohm/km	Susceptance mho/km
Zero :	2.31591E-01	7.83594E-01	2.85977E-06
Positive:	2.49312E-02	2.80664E-01	4.12574E-06

$Z_{N3} = Z_G \,//\, Z_{OPGW} = R_{N3} + X_{N3} = (0{,}0689 + j\,0{,}1676)\ \Omega/km$

Using the same procedure we get:

$$Z_{OPGW} = (Z_G * (Z_G \,//\, Z_{OPGW})) / (Z_G - (Z_G \,//\, Z_{OPGW}))$$
$$= \underline{0{,}3853\ \Omega/km + j\,0{,}3607\ \Omega/km}$$

Summarizing, we get the following values for Z_G, Z_{GW} and Z_{OPGW}.

Z_G	$= (0{,}0475 + j\,0{,}2537)\ \Omega/km$
Z_{GW}	$= (1{,}0848 + j\,0{,}2347)\ \Omega/km$
Z_{OPGW}	$= (0{,}3853 + j\,0{,}3607)\ \Omega\ /km$

Just to corroborate these results, we will use the sequence parameters taking the whole line into consideration, i.e., with both ground wires and OPGW we can get:

<u>4) Both ground wires and the OPGW</u>

Sequence	Resistance ohm/km	Reactance ohm/km	Susceptance mho/km
Zero :	2.68081E-01	7.10796E-01	3.06749E-06
Positive:	2.57099E-02	2.80507E-01	4.15344E-06

$Z_{N4} = Z_G \,//\, Z_{GW} \,//\, Z_{OPGW} = R_{N4} + X_{N4} =$
$(0{,}0808 + j\,0{,}1434)\ \Omega/km$

If we start from case 2, both ground wires and no OPGW we get: $Z_G \,//\, Z_{GW} = (0{,}0860+ j\,0{,}2158)\ \Omega/km$

Proceeding the same way, we get: Z_{OPGW}

$$= ((Z_G//Z_{GW})*(Z_G//Z_{GW}//Z_{OPGW})) / ((Z_G//Z_{GW}) – (Z_G//Z_{GW}//Z_{OPGW}))$$

$$Z_{OPGW} = \boxed{(0{,}3856 + j\ 0{,}3597)\ \Omega/km}$$

This result is quite close to the one that has already been calculated, which was:

$$Z_{OPGW} = \boxed{(0{,}3853 + j\ 0{,}3607)\ \Omega/km}$$

This way, the methodology to determine the ground return impedance for each element of a line, either ground wires or OPGW using the Sequence Parameter Method has been validated.

B. Determining the fault current on the OPGW

Starting with the short circuit programs, the fault current is available on a specific point on the network as well as the components that make that current.

If a fault occurs in a point of the studied line, each component is derived for its own ground return, which, as said above, is the parallel of "the ground", both ground wires and the OPGW.

It has also been stated that, due to the presence of tower-footing resistances, this current will flow (in the proximity of the fault) almost totally through both ground wires and the OPGW.

Assuming this position, even though it is not exact, leads to conservative results whenever evaluating the current that will flow through the OPGW.

Thus, the results obtained:

Z_{GW} = (1,0848 + j 0,2347) Ω/km

Z_{OPGW} = (0,3853 + j 0,3607) Ω/km

That is how we get to:

$I_{OPGW} = [(1 / Z_{OPGW}) / [(1 / Z_{OPGW}) + (1 / Z_{GW})]] * I_{CC}$

$I_{OPGW} = [Z_{GW} / (Z_{GW} + Z_{OPGW})] * I_{CC}$

Being I_{CC}, the fault current and, I_{OPGW} the component of the fault current that goes through the OPGW.

Similarly, the component of the fault current that goes through both ground wires is:

$I_{GW} = [Z_{OPGW} / (Z_{GW} + Z_{OPGW})] * I_{CC}$

It will get:

$I_{OPGW} = (0{,}689 - j\ 0{,}120) * I_{CC} = (0{,}700\ \angle -9{,}84º)\ I_{CC}$.

$I_{GW} = (0{,}311 + j\ 0{,}120) * I_{CC} = (0{,}333\ \angle 21{,}06º)\ I_{CC}$.

According to this, the current that goes through the OPGW is 70% of the fault current.

The OPGW to be used is dimensioned for a 20.6 kA short circuit current during 125 ms.

According to the short circuit surveys developed for Ezeiza, which is the most critical node of the network, it is a single phase to ground fault current of 26080 A.

Based on these results, the current that will pass through the OPGW, in the event of this extreme circumstance, will be of 26080 A * 0.70 = 18260 A, lower than the 20600 A that this OPGW can withstand for 125 ms.

C. Not taking the tower-footing resistances into account

This analysis is made only to show the influence of the tower-footing resistances in the magnitude of currents on the OPGW and on both ground wires.

We already had:

Z_G = (0,0475 + j 0,2537) Ω /km

Z_{GW} = (1,0848 + j 0,2347) Ω /km

Z_{OPGW} = (0,3853 + j 0,3607) Ω /km

Operating, we have:

$Z_G // Z_{GW}$ = (0,0860 + j 0,2158) Ω /km

$Z_G // Z_{OPGW}$ = (0,0689 + j 0,1676) Ω /km

$Z_{GW} // Z_{OPGW}$ = (0,3088 + j 0,2026) Ω /km

$Z_G // Z_{GW} // Z_{OPGW}$ = (0,0808 + j 0,1434) Ω /km

To get the magnitude of the current that will go on each return way we have:

$I_{OPGW} = [(Z_G // Z_{GW}) / ((Z_G // Z_{GW}) + Z_{OPGW})] * I_{CC}$

$I_{GW} = [(Z_G // Z_{OPGW}) / ((Z_G // Z_{OPGW}) + Z_{GW})] * I_{CC}$

$I_G = [(Z_{GW} // Z_{OPGW}) / ((Z_{GW} // Z_{OPGW}) + Z_G)] * I_{CC}$

When replacing the values, we get:

$I_{OPGW} = (0{,}297 + j\ 0{,}094) * I_{CC} = (0{,}312\ \angle 17{,}53º)\ I_{CC}$

$I_{GW} = (0{,}098 + j\ 0{,}111) * I_{CC} = (0{,}148\ \angle 48{,}43º)\ I_{CC}$

$I_G = (0{,}604 - j\ 0{,}205) * I_{CC} = (0{,}638\ \angle -18{,}74º)\ I_{CC}$

From this, we can say that:

If the tower-footing resistances are not taken into account, a great portion of the fault current would go by "the ground" (approximately 60%), and only 30% of the fault current would go by the OPGW.

In a real stage, tower-footing resistances are always present, and therefore, a high percentage of the fault current will flow by the OPGW.

A confirmation of this statement is shown using the Short Line Simulation Method with ATP Program

IV. SHORT LINE SIMULATION METHOD

A. To rule out "the ground" return current, due to tower-footing resistance.

Here we will verify the currents that go by the OPGW and both ground wires (not considering "the ground" return due to tower-footing resistances) using the Short Line Simulation Method with distributed parameters.

In order to do it, we will adopt the circuital scheme.

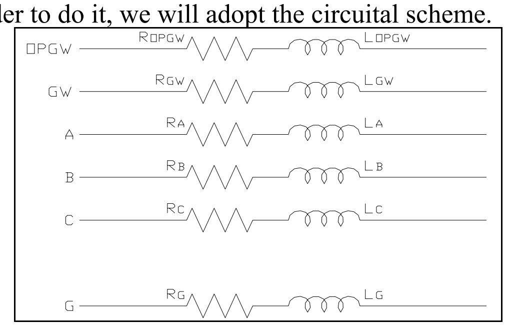

Fig. 4. Circuital scheme to use the Short Line Simulation Method, where the OPGW and ground wires are simulated as additional conductors, not grounded ones.

a) To create a truthful stage on a critical situation, a 400 m short section of line (span) with distributed parameters is represented for this study.

b) To determine the current that goes by the OPGW and by both ground wires we will represent them as additional conductors, not grounded ones.

c) We will simulate the current on one end of the section (span beginning) and, on one phase, an injection of current of:

$\sqrt{2}\ I_{CC} = (\sqrt{2} * 26080\ \text{A})\ \text{COS}\ (2\ \Pi\ 50\ t + 0^{o})$.

This current comes from a parallel made by the OPGW and both ground wires.

d) On the other end of the section the fault is schemed by causing short-circuit on the phase with the parallel of the OPGW and both ground wires.

The following Fig. shows the diagram explained above.

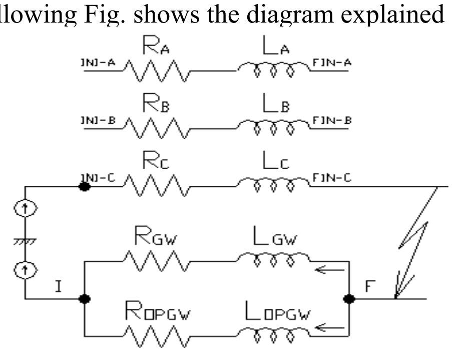

Fig. 5. Simulation of the failure taking into account ground return only by the OPGW and both ground wires, due to the presence of tower-footing resistances

In the Figure 11 of the Appendix it is shown the data entry to the program in order to determine the sequence parameters of the line with additional conductors (OPGW e both ground wires), that is according to what has been stated above.

In the Figure 12 of the Appendix it is shown partial input data file of the line, with its OPGW and both ground wires, with its five propagation modes, including the parallel of the OPGW and both ground wires, the fault on phase C with the injection of the fault current, represented by two current sources.

The output, with the sinusoidal steady-state phasor solution is shown in the Figure 13 of the Appendix

It is shown that the portion of the fault current that goes by the OPGW is:

$I_{OPGW} = 24542 / (\sqrt{2} * 26080) = (0{,}665 \angle -8{,}84^{o})\ I_{CC}$

Similarly, the fault current by both ground wires is:

$I_{GW} = 13180 / (\sqrt{2} * 26080) = (0{,}357 \angle 16.63^{o})\ I_{CC}$

The values that were taken using the Sequence Parameter Method described before were:

$I_{OPGW} = (0{,}700 \angle -9{,}84^{o})\ I_{CC}$
$I_{GW} = (0{,}333 \angle 21{,}06^{o})\ I_{CC}$

If we diagram the results on a table we will get:

TABLE I
COMPARISON ON BOTH METHODS USED TO DETERMINE THE FAULT CURRENT BY THE OPGW AND BY BOTH GROUND WIRE S

Method	I_{OPGW}	I_{GW}
Sequence Parameter Method	$(0.700 \angle -9.84^{o})I_{CC}$	$(0{,}333 \angle 21{,}06^{o})\ I_{CC}$
Short Line Simulation Method	$(0{,}665 \angle -8{,}84^{o})I_{CC}$	$(0{,}357 \angle 16.63^{o})\ I_{CC}$

When doing the comparison, it is shown that there is a little difference in the results when using both methods.

This can be explained because in the sequence parameter method, there is a symmetrized transmission line with two propagation modes, positive and homopolar sequences.

On the other hand, in the Short Line Simulation Method there is an asymmetry, which provokes five propagation modes.

B. Not taking the tower-footing resistances into account:

The same study for Short Line Simulation Method is developed, but this time assuming that there is no tower-footing resistance. This is made just to compare the analysis methods (Sequence Parameters Method and Short Line Simulation Method).

In order to do it, the parallel for the OPGW and both ground wires are grounded on both ends of the section.

The following Fig. shows the diagram.

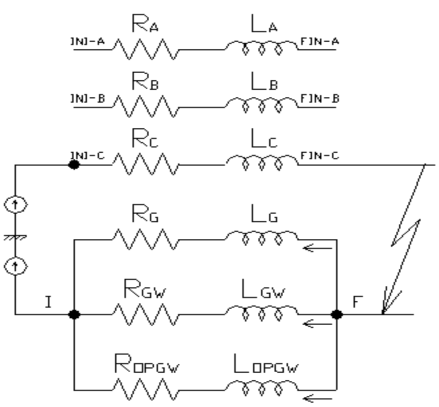

Fig. 6. Simulating a fault taking into account "the ground", the OPGW and both ground wires, due to not taking the tower-footing resistance into account.

For this case (as seen in the analysis when "the ground" returns current is ruled out due to tower-footing resistances), results from the sinusoidal steady-state phasor solution are:

The fault current through the OPGW is:

$$\boxed{I_{OPGW} = (0{,}335 \angle 21.98^{o}) * I_{CC}}$$

The fault current through both ground wires is:

$$\boxed{I_{GW} = (0{,}112 \angle 42.22^{o}) * I_{CC}}$$

And the fault current through "the ground" is:

$$\boxed{I_{G} = (0{,}639 \angle -18.29^{o}) * I_{CC}}$$

The values using the Sequence Parameters Method shown before were:

$I_{OPGW} = (0,297 + j\ 0,094) * I_{CC} = (0,312 \angle 17,53º) * I_{CC}$

$I_{GW} = (0,098 + j\ 0,111) * I_{CC} = (0,148 \angle 48,43º) * I_{CC}$

$I_{G} = (0,604 - j\ 0,205) * I_{CC} = (0,638 \angle -18,74º) * I_{CC}$

If we diagram the results on a table we will get:

TABLE II

COMPARING BOTH METHODS IN THE DETERMINATION OF THE FAULT CURRENT THROUGH THE OPGW, BOTH GROUND WIRES AND "THE GROUND"

Method	I_{OPGW}	I_{GW}	I_{G}
Sequence Parameter Method	[0,312 $\angle$ 17,53º] $*I_{CC}$	[0,148 $\angle$ 48,43º] $*I_{CC}$	[0,638 $\angle$ -18,74º] $*I_{CC}$
Short Line Simulation Method	[0,335 $\angle$ 21.98º] $*I_{CC}$	[0,112 $\angle$ 42.22º] $*I_{CC}$	[0,639 $\angle$ -18.29º] $*I_{CC}$

As expressed on the previous case, the differences can be explained because in the Sequence Parameter Method there is a symmetrized transmission line. That is not the case with the Short Line Simulation Method, where asymmetries occur.

C. Taking the tower-footing resistances into account

The procedure is the same, but, instead of assuming a null tower-footing resistance we use the typical value 5Ω.

Using the same model, a simulation is staged

The following Fig shows the diagram.

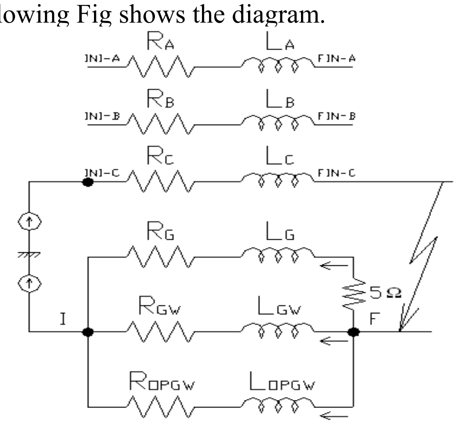

Fig. 7. Simulating a failure taking "the ground", the OPGW and both ground wires into account, and assuming a 5Ω resistance

For this case, with the tower-footing resistance included, the results on the sinusoidal steady-state phasor solution are:

The fault current through the OPGW is:

$$\boxed{I_{OPGW} = (0,648 \angle -9.56º) * I_{CC}}$$

The fault current through both ground wires is:

$$\boxed{I_{GW} = (0,348 \angle 15.38º) * I_{CC}}$$

And the fault current through "the ground" is:

$$\boxed{I_{G} = (0,030 \angle 31.34º) * I_{CC}}$$

If a 5Ω tower-footing resistance is assumed, "the ground" return current will be reduced to 3% of the fault current, therefore, almost all the current will go through the other ways of return: the OPGW and both ground wires.

It is important to compare these magnitudes with those obtained when using the Short Line Simulation Method, which assumed no current by "the ground" return due to the presence of tower-footing resistances.

TABLE III

SHORT LINE SIMULATION METHOD (SPAN), - COMPARISON BETWEEN THE CURRENTS ON "THE GROUND", THE OPGW AND BOTH GROUND WIRES

	I_{OPGW}	I_{GW}	I_{G}
Discarded "the ground" currents	[0,665 $\angle$ -8,84º] $*I_{CC}$	[0,357 $\angle$ 16.63º] $*I_{CC}$	-
With 5 Ω tower-footing resistances	[0,648 $\angle$ -9.56º] $*I_{CC}$	[0,348 $\angle$ 15.38º] $*I_{CC}$	[0,030 $\angle$ 31.34º] $*I_{CC}$

We can observe, from the comparison, that the results are very close. Nevertheless, there is a slight higher values in the (OPGW and both ground wires) return currents in the case with no "the ground" return current, than in the case with a 5Ω tower-footing resistance.

This is why assuming no current by "the ground" will lead to an approximation of the truth, letting conservative speculations arise

V. CONCLUSIONS:

In this work two procedures for analysis to determine how the fault current returns through the OPGW and both ground wires were shown.

In the Sequence Parameters Method, two studies were made:

1^{st}) Assuming that due to the presence of tower-footing resistances there will be no current through "the ground", and that all the fault current will go through the OPGW and both ground wires.

2^{nd}) Assuming null tower-footing resistances, in this case the fault current will return through "the ground", the OPGW and both ground wires.

If we compare the results on both analyses, the currents that go through the OPGW and both ground wires are very sensitive to the assumptions.

In the first case the value for the currents was much higher (over the double) than the values assuming no tower-footing resistances, where a great portion of the current goes by "the ground".

In the Short Line Simulation Method, three studies were performed:

1^{st} y 2^{nd}) Matching the assumptions used for the sequence method, same results as the ones from the previous method arise. The values are not exactly the same as the prior ones, but they are very close. This slight variation is due to the asymmetries in the Short Line Simulation Method. That is not the case in Sequence Parameters Method.

3^{rd}) In this case, a 5 Ω tower-footing resistance was simulated at one end, and the results are similar to the ones in the case in which "the ground" return current is ruled out.

Because of the above-explained it can be concluded that the simple proposal based on assuming that, in the event of single phase to ground fault, the fault current in (the proximity of the fault) will return only by the OPGW and both ground wires.

VI. Appendix

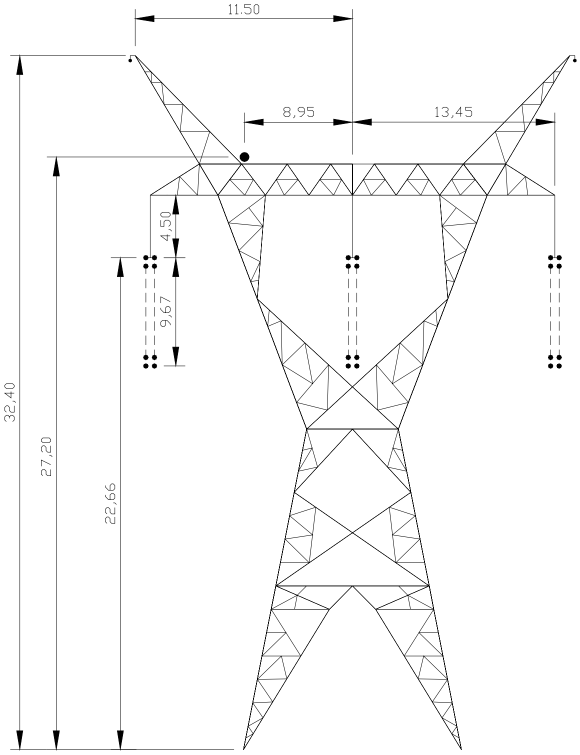

Fig. 8 Diagram of the tower, with the position of the OPGW, both ground wires and conductors.

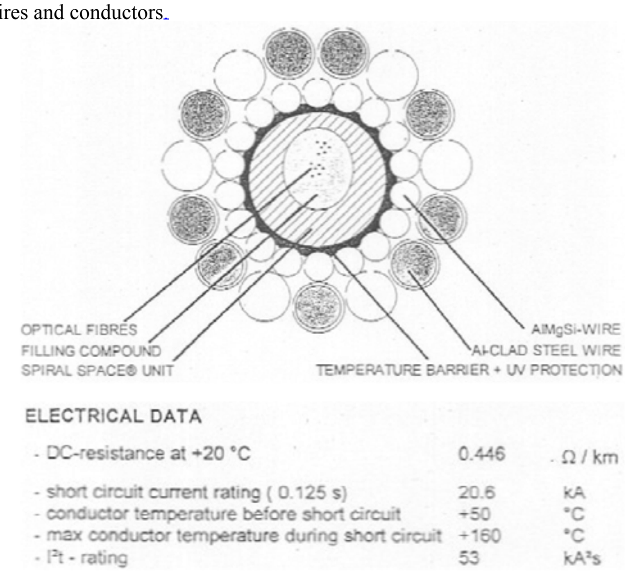

Fig. 9 Conformation and Electrical Data of the OPGW

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LINE CONSTANTS
C
METRIC
C ><SKN>< RESIS>IX< REACT>< DIAM >< HORIZ><VTOWER>< VMID >< SEPAR><ALPH>      NB
  1 .316  0.0951 4           2.450  -13.45   22.66  12.99      45.   45.       4
  2 .316  0.0951 4           2.450    0.00   22.66  12.99      45.   45.       4
  3 .316  0.0951 4           2.450   13.45   22.66  12.99      45.   45.       4
  0 .5    2.20   4           1.250  -11.50   32.40  23.70
  0 .5    2.20   4           1.250   11.50   32.40  23.70
  0 .264  0.446  4           1.490    8.95   27.20  17.53
```

Fig. 10 Data entry to the ATP Program,

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LINE CONSTANTS
C
METRIC
C ><SKN>< RESIS>IX< REACT>< DIAM >< HORIZ><VTOWER>< VMID >< SEPAR><ALPH>      NB
  1 .316  0.0951 4           2.450  -13.45   22.66  12.99      45.   45.       4
  2 .316  0.0951 4           2.450    0.00   22.66  12.99      45.   45.       4
  3 .316  0.0951 4           2.450   13.45   22.66  12.99      45.   45.       4
  4 .5    2.20   4           1.250  -11.50   32.40  23.70
  4 .5    2.20   4           1.250   11.50   32.40  23.70
  5 .264  0.446  4           1.490    8.95   27.20  17.53
BLANK
C
    100.       50.         1      1   1       .4         0          1
```

Fig. 11. Input data file to determine sequence parameters in the Short Line Simulation Method.

```
-1INI-A FIN-A               1.02720E+00 2.66086E+02 2.77805E+05-1.00000E+00 1  5
-2INI-B FIN-B               2.40533E-01 7.25064E+02 1.87817E+05-1.00000E+00 1  5
-3INI-C FIN-C               3.37658E-01 3.72341E+02 2.92343E+05-1.00000E+00 1  5
-4I-GW  F-GW                2.56217E-02 2.85669E+02 2.87934E+05-1.00000E+00 1  5
-5I-OPGWF-OPGW              2.39039E-02 2.39352E+02 2.97288E+05-1.00000E+00 1  5
...............................................................................
...............................................................................
C  CONNECTION TO TOWER FROM BOTH GROUND WIRES AND THE OPGW WITH
C  1 MILIOHM RESISTANCE

C
  I-GW  I-OPGW              0.001
  F-GW  F-OPGW              0.001
C
C  A SINGLE PHASE TO GROUND FAULT AT THE END OF THE SECTION WITH
C  1 MILIOHM RESISTANCE

C
  FIN-C F-GW                0.001
BLANK
BLANK
C
C   A FAULT CURRENT IS REPRESENTED AS A SOURCE CURRENT ON
C   PHASE A IT RETURNS BY BOTH GROUND WIRES AND THE OPGW

C
14INI-C -1    36880.       50.      0.00                              -1.      10.
14I-GW  -1    36880.       50.   -180.00                              -1.      10.
```

Fig. 12. Input data file to determine the fault current by the OPGW using Short Line Simulation Method

```
Bus K                        Phasor  branch   current
           Bus M           Rectangular              Polar

I-GW                    -12629.28239914   13180.845425752
                        -3773.050784221     -163.3662652

           F-GW         12629.284794932   13180.847191287
                        3773.0489327004       16.6337241

I-OPGW                  -24250.71760086   24542.477796199
                        3773.0507842212      171.1565316

           F-OPGW       24250.719174098   24542.479537652
                        -3773.052000056       -8.8434706
```

Fig. 13. Output with the sinusoidal steady-state phasor solution, it is shown fault current on the OPGW and both ground wires, using Short Line Simulation Method

VII. References

[1] Alternative Transient Program (ATP)- Rule Book

[2] Electro – Magnetic Transients Program (EMTP) Theory Book - Second Edition – Hermann W. Dommel

[3] The Calculation of Short Circuit Currents in Overhead Ground Wires Using the EMTP/ATP - Marco Polo Pereira, Paulo Cesar Vaz Esmeraldo International Conference on Power Systems Transients IPST 2001

[4] Technical Brochure - Optical Ground Wire (OPGW) AACSR/AW SS-nF 58/44

[5] Electrical Transients in Power Systems – Allan Greenwood - Second Edition

VIII. Biography

Héctor R. Disenfeld was born in Tucumán - Argentina, on May 19, 1947. He received his degree of Electrical Engineer from the Universidad Nacional de Tucumán in 1971. He is with Transener S.A, company in the public service of the extra high voltage electric power transmission system in the Argentine Republic. His main working areas include simulation of electromagnetic transients in power systems and HV insulation co-ordination.