MULTI-REGION SOIL MODEL FOR ELECTROMAGNETIC INTERFERENCES ANALYSIS

Maxime Daigle[1], Simon Fortin[1] and François Grange[2]

[1]Safe Engineering Services & technologies ltd.
[2]SES-Europe.
Email: francois.grange@sestech.fr Web Site: www.sestech.fr

Abstract

One of the main limitations of the HIFREQ computation engine is that a single soil model must apply to the whole network. However, when conductor networks reach a certain size, multiple, multi-layer soil models for various portions of the system become relevant. This paper presents an expanded version of the HIFREQ engine, which can take into account multiple soil models. The results obtained through this new approach are compared to other calculation methodologies for validation.

1 Introduction

Many complex grounding systems consist of a network of conductors which cannot be assumed to be in a single of the soil models currently available in MALT, MALZ or HIFREQ. Windfarms, for example, include many turbine footings in different multilayer soils, interconnected by insulated cables. It is now common for studies of electromagnetic interference in joint-use corridors to stretch well over one hundred kilometers and it is essential for such models to correctly take into account variations in soil structures along the corridor to properly compute leakage impedances and through earth coupling between buried metallic structures.

While solutions exist for a rather large variety of different soils (for example, all the different soil models available in MALT, MALZ and HIFREQ) these same solutions cannot be used to treat multiple regions. In principle one has the option of using finite volumes, but in practice the resources required can be prohibitive. A complete solution to this theoretical problem is quite challenging, and while work has begun on a technique that uses a Boundary-Element Method to handle the boundary conditions between the different regions [1] (for use in MALT and MALZ, but not HIFREQ), it is still far from being included in the software.

There are some workarounds to the current limitation in MALT, MALZ and HIFREQ to a single soil model. With the clever use of lumped impedances the effect of remote grounds can be included, though these need to be calculated in separate models. For long joint-use corridors, the Right-of-Way module can add a leakage correction to a conductor by way of a connection to remote earth through a specified lead impedance. If the configuration or characteristics of the conductor changes for a given phase along the corridor though, the leakage impedance correction cannot be based on the SPLITS model. Right-of-Way needs to recompute the leakage correction at the time of the MALZ total interference file generation, which can take substantial computation time. Moreover, studying objects like pipeline valve stations for faults that are not in the same soil as the fault location remains problematic. A multi-region soil computation capability is still needed. [2]

A simplified approach that consists of enhancing the HIFREQ module to allow the specification of multiple soil regions, though short of a full solution, has been considered for some time. This paper presents the very promising results of the implementation of this simplified model, which could be a substantial improvement to the current methodology.

2 The Proposed Computation Methodology

In the presence of a multi-layer soil, a conductor's leakage impedance will be influenced by all layers. Likewise, when computing the influence of leakage current from one conductor on another, whether both are in the same soil layer or not, all soil layers will have an influence on the result.

While solving the horizontal multi-layered multi-region model exactly is not yet within our grasp, a simplified model has been proposed. The simplification consists of performing the calculation of the leakage current for a given conductor segment assuming that only the horizontally multi-layered soil in which that conductor sits exists, and that the contributions from one soil region to another soil region are determined by the source soil only; namely, we simply ignore all other soils. Consider a standard case of a long, buried conductor crossing several soil regions, sketched in Figure 1.

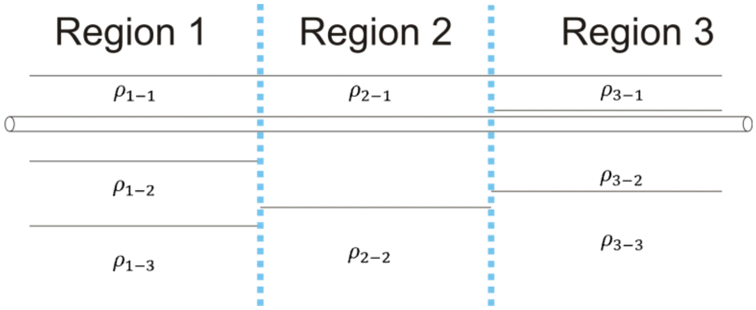


Figure 1: Standard case of long conductor that crosses three horizontally layered soil regions.

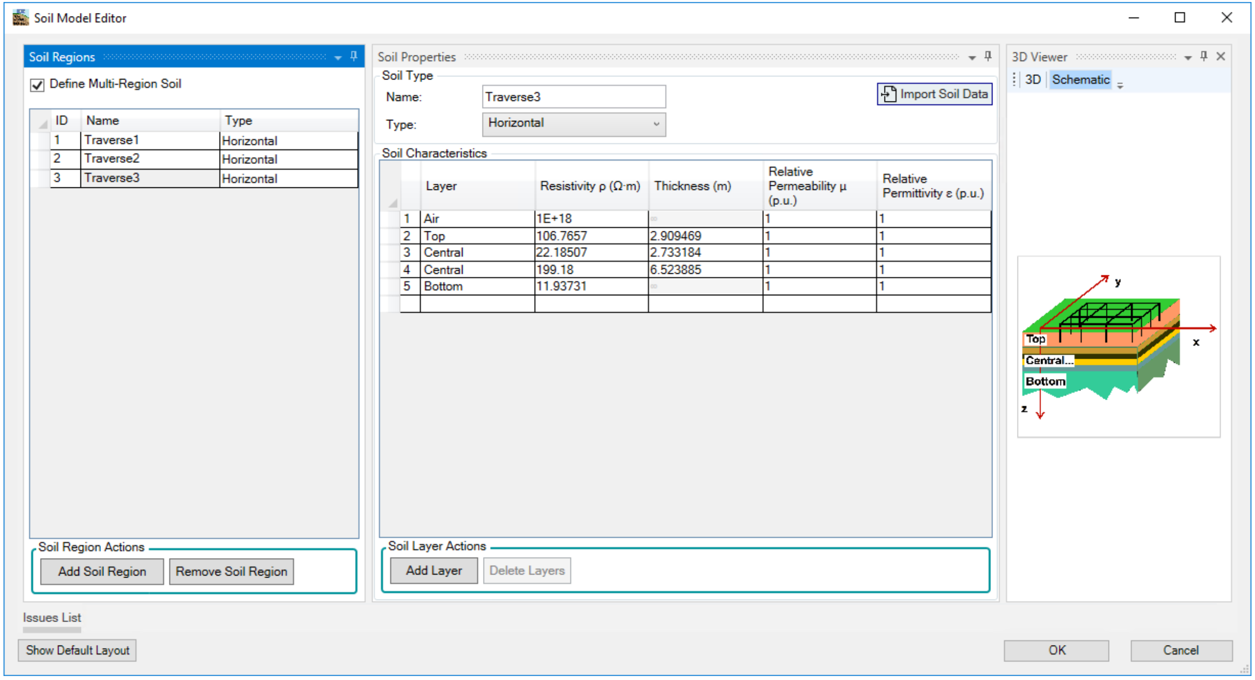
The contribution from a conductor segment located in soil Region 3 to the potential at a point in soil Region 1 is influenced by Regions 1 and 3 but also by Region 2. In this simplified model, we ignore that influence. The contribution from a conductor segment in soil Region 3 at a point in any soil region will be computed as if the soil of Region 3 applies everywhere.

The simplification basically assumes that the local contributions will dominate, and consequently, that the approximate portion of the calculation is not substantial enough to have a large influence on the results. This is quite reasonable for cases where the boundary area between different soil regions is not of particular interest, for example electrodes separated by a large enough distance that independent sets of resistivity measurements are used to determine the local soil models, or joint use corridors that consist of soil changes along the corridor such that only small portions of the model straddle the soil boundary and do so orthogonally, minimizing the cross-boundary conductive coupling.

The major advantages of this methodology are that it is easier to implement than the more complete numerical solution described above and is not more costly in computation resources (memory or time). While a complete solution is naturally more desirable, this simpler method opens up key modeling possibilities for more detailed studies and has the added benefit of being easier to use than the current best practices.

3 Using Multi-Region Soils with SESCAD

Taking advantage of the new computational methodology will be quite intuitive for users already experienced in using **SESCAD**. The soil models can be created, modified and imported in the same way as they used to by going to **Define| Soil Model**, where a new soil structure panel lists the defined soil models, as shown in Figure 2. To do so, the Soil Model Editor must be set to **Component** (as opposed to **Built-In**) in the **General Settings| Interaction** options. The **Define Multi-Region Soil** checkbox allows to toggle between this extended mode and the classical one where only one soil model is permitted. When the Multi-region option is turned on, the next action is to define where the various soil models will apply. To do so, a new characteristic named **Soil Region ID** was created and can be used in the same way as coating or conductor



☑ Define Multi-Region Soil

ID	Name	Type
1	Traverse1	Horizontal
2	Traverse2	Horizontal
3	Traverse3	Horizontal

Soil Type

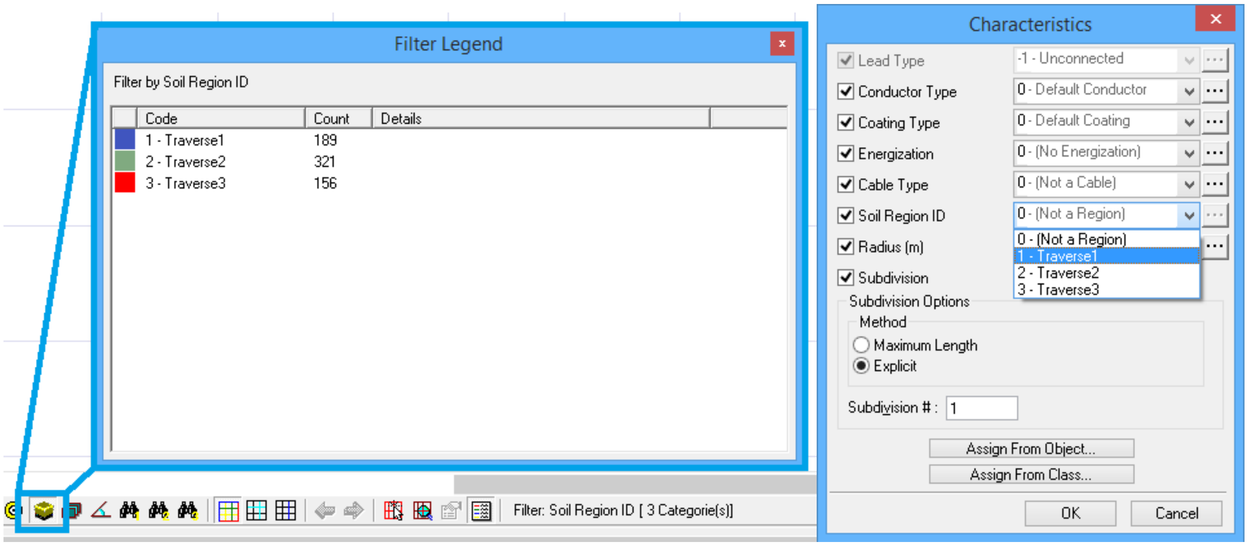
Name: Traverse3

Type: Horizontal

Soil Characteristics

	Layer	Resistivity ρ (Ω·m)	Thickness (m)	Relative Permeability μ (p.u.)	Relative Permittivity ε (p.u.)
1	Air	1E+18	∞	1	1
2	Top	106.7657	2.909469	1	1
3	Central	22.18507	2.733184	1	1
4	Central	199.18	6.523885	1	1
5	Bottom	11.93731	∞	1	1

Figure 2: The expanded Soil Model Editor window.



Filter by Soil Region ID

	Code	Count	Details
🟦	1 - Traverse1	189	
🟩	2 - Traverse2	321	
🟥	3 - Traverse3	156	

Filter: Soil Region ID [3 Categorie(s)]

☑ Lead Type: -1 - Unconnected
☑ Conductor Type: 0 - Default Conductor
☑ Coating Type: 0 - Default Coating
☑ Energization: 0 - (No Energization)
☑ Cable Type: 0 - (Not a Cable)
☑ Soil Region ID: 0 - (Not a Region)
- 0 - (Not a Region)
- 1 - Traverse1
- 2 - Traverse2
- 3 - Traverse3

☑ Radius (m)
☑ Subdivision

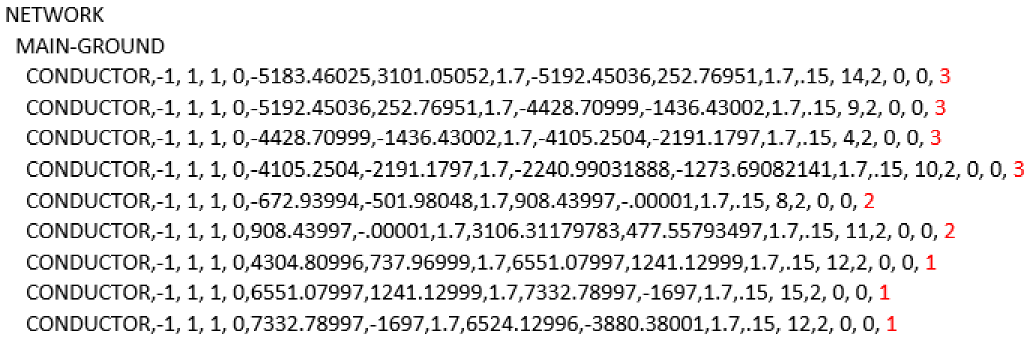
○ Maximum Length
● Explicit

Subdivision # : 1

Figure 3: The Soil Region ID is managed as a conductor characteristic and can be assigned and filtered as usual.

types are assigned. Note that every conductor in the model must be assigned a non-zero Soil Region ID when the Multi-region option is active. As a new conductor characteristic, the Soil Region ID offers the familiar filtering options as other conductor characteristics in **SESCAD**, such as conductor type or coating type. However, **SESResultsViewer** does not yet support the Soil Region ID, although it should be implemented soon. The way the subsurface resistivity will be selected for safety calculation remains to be decided.

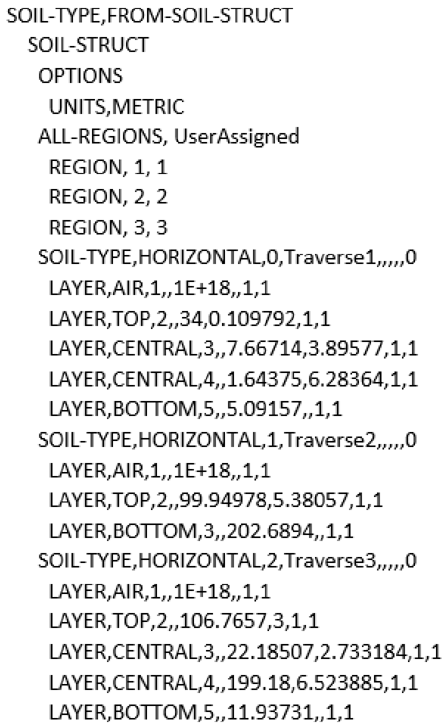
If you take a look at the f05 file using the multi-region approach, you will only see subtle changes. First, each CONDUCTOR command now carries an additional variable corresponding to the soil region ID, this variable is placed at the very end of the command line, as shown in Figure 4.



```
NETWORK
 MAIN-GROUND
  CONDUCTOR,-1, 1, 1, 0,-5183.46025,3101.05052,1.7,-5192.45036,252.76951,1.7,.15, 14,2, 0, 0, 3
  CONDUCTOR,-1, 1, 1, 0,-5192.45036,252.76951,1.7,-4428.70999,-1436.43002,1.7,.15, 9,2, 0, 0, 3
  CONDUCTOR,-1, 1, 1, 0,-4428.70999,-1436.43002,1.7,-4105.2504,-2191.1797,1.7,.15, 4,2, 0, 0, 3
  CONDUCTOR,-1, 1, 1, 0,-4105.2504,-2191.1797,1.7,-2240.99031888,-1273.69082141,1.7,.15, 10,2, 0, 0, 3
  CONDUCTOR,-1, 1, 1, 0,-672.93994,-501.98048,1.7,908.43997,-.00001,1.7,.15, 8,2, 0, 0, 2
  CONDUCTOR,-1, 1, 1, 0,908.43997,-.00001,1.7,3106.31179783,477.55793497,1.7,.15, 11,2, 0, 0, 2
  CONDUCTOR,-1, 1, 1, 0,4304.80996,737.96999,1.7,6551.07997,1241.12999,1.7,.15, 12,2, 0, 0, 1
  CONDUCTOR,-1, 1, 1, 0,6551.07997,1241.12999,1.7,7332.78997,-1697,1.7,.15, 15,2, 0, 0, 1
  CONDUCTOR,-1, 1, 1, 0,7332.78997,-1697,1.7,6524.12996,-3880.38001,1.7,.15, 12,2, 0, 0, 1
```

Figure 4: New structure for the CONDUCTOR command, highlighting the Soil Model ID.

The SOIL-TYPE command is now a repetitive command nested inside the new SOIL-STRUCT parent command. A typical SOIL-TYPE command block is presented in Figure 5.



```
SOIL-TYPE,FROM-SOIL-STRUCT
  SOIL-STRUCT
   OPTIONS
    UNITS,METRIC
   ALL-REGIONS, UserAssigned
    REGION, 1, 1
    REGION, 2, 2
    REGION, 3, 3
   SOIL-TYPE,HORIZONTAL,0,Traverse1,,,,,0
    LAYER,AIR,1,,1E+18,,1,1
    LAYER,TOP,2,,34,0.109792,1,1
    LAYER,CENTRAL,3,,7.66714,3.89577,1,1
    LAYER,CENTRAL,4,,1.64375,6.28364,1,1
    LAYER,BOTTOM,5,,5.09157,,1,1
   SOIL-TYPE,HORIZONTAL,1,Traverse2,,,,,0
    LAYER,AIR,1,,1E+18,,1,1
    LAYER,TOP,2,,99.94978,5.38057,1,1
    LAYER,BOTTOM,3,,202.6894,,1,1
   SOIL-TYPE,HORIZONTAL,2,Traverse3,,,,,0
    LAYER,AIR,1,,1E+18,,1,1
    LAYER,TOP,2,,106.7657,3,1,1
    LAYER,CENTRAL,3,,22.18507,2.733184,1,1
    LAYER,CENTRAL,4,,199.18,6.523885,1,1
    LAYER,BOTTOM,5,,11.93731,,1,1
```

Figure 5: The SOIL-STRUCT command block.

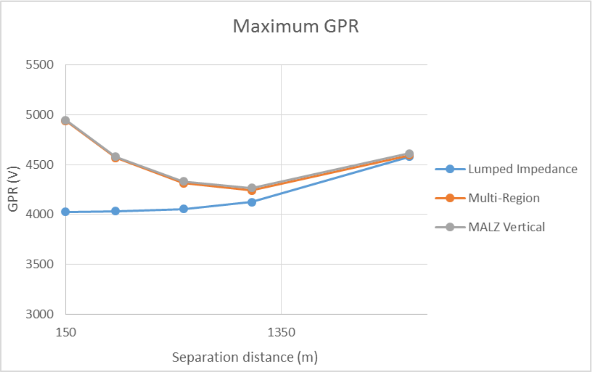
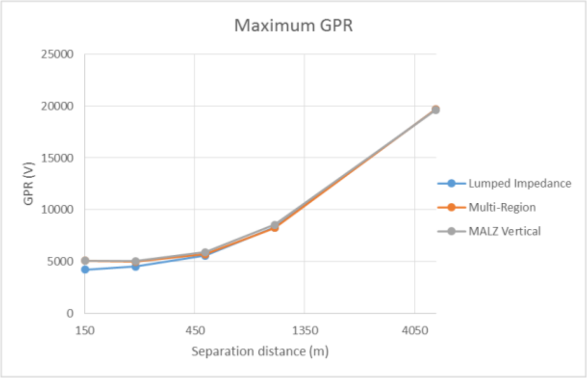
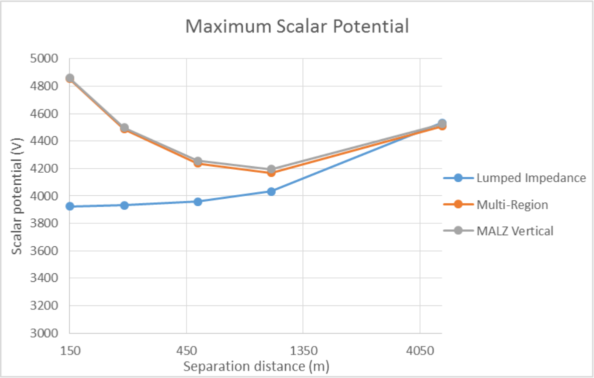
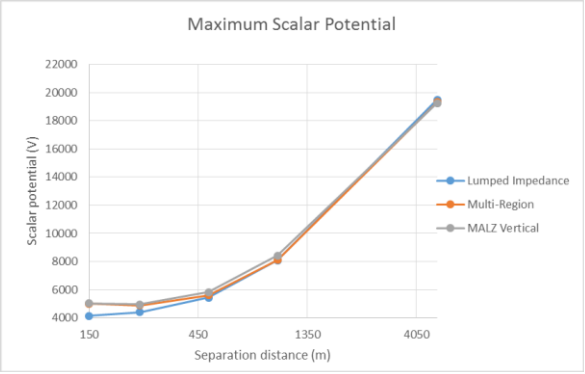
Note that these new multi-region commands are not supported by the CDEGS-Legacy version, they will be lost if the file is opened in Input Toolbox.

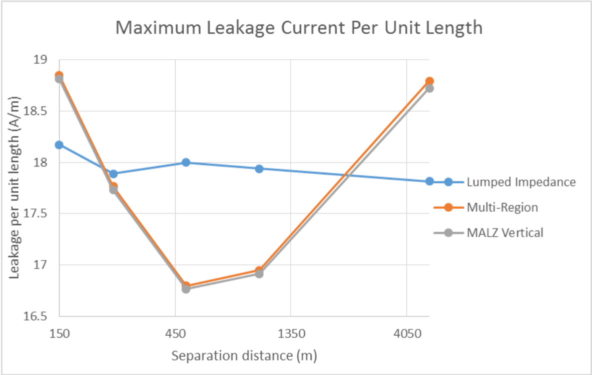
4 Validation

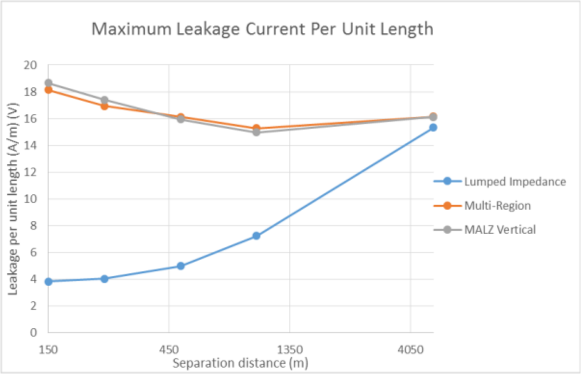
4.1 Simple Two Grids Model

It is always a challenge to validate results from a new algorithm expanding the capabilities of a computational module since we need to find an already validated method to use as a reference for comparison. In our case, one possible validation approach is to take advantage of the vertical soil model available in the MALZ computational engine. This approach entails that we only use uniform soils definitions for the Multi-Region model. Let us consider two identical 100 m * 100 m grids buried in different uniform soils and connected through a single insulated buried conductor. One grid will be energized with current and the second one will serve as an auxiliary grounding system. We will compare the HIFREQ Multi-Region solution to results obtained with MALZ vertical soils and also to an HIFREQ model where the auxiliary grid is replaced with a lumped impedance connected to a zero GPR energization. We can expect the three solutions to yield similar results at large distance, but the lumped impedance solution will should become increasingly inaccurate as the distance between the two grids is reduced because of the through-soil interaction between the two grids this model is neglecting. The analysis was performed for a case where the energized grid is buried in 100 Ω·m soil while the auxiliary grid is buried in 500 Ω·m soil and also with the opposite situation. Three quantities were monitored: the maximum conductor GPR, the maximum scalar potential and the maximum leakage current per unit length (all conductors in the model have the same radius). Table 1 summarizes the results:

Table 1: Results comparison for the three computation approaches.

<table>
<tr><th>Energized grid in 100 Ω·m</th><th>Energized grid in 500 Ω·m</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>





As can be seen, the three models compute the same maximum GPR and scalar potential at large separation distance, but the lumped impedance approach starts to diverge from the other two solutions for a separation distance as large as 1000 m. The multi-region solution remains almost identical to the MALZ vertical soil solution for every separation distance. Note that the separation distance is measured between the centers of the grids, meaning the edges of the grids are separated by a mere 50 m in the closest case. The maximum leakage current is also accurately computed by the multi-region algorithm while the lumped impedance approach can yield inaccurate values even at a separation distance of 5000 m.

4.2 Complex System Comparison

To assess the performances of the multi-region soil model computation algorithm involving multilayer soils, the only standard that can be used is to construct a Right-of-Way model which has built-in corrections to circumvent the limitations of using a single soil model for each total interference model. We already know that the corrections performed by ROW are not perfect, since the tower footing impedance will be incorrect for every tower that lies in a different soil region than the one where the fault occurs. This must be kept in mind when comparing the results obtained with the two methods. The system under study is made of a single, perfectly straight transmission line and a coated pipeline that approaches the transmission line at an angle, then parallels the transmission line at a distance of 15 m for 8.1 km, crosses the transmission line, then continues

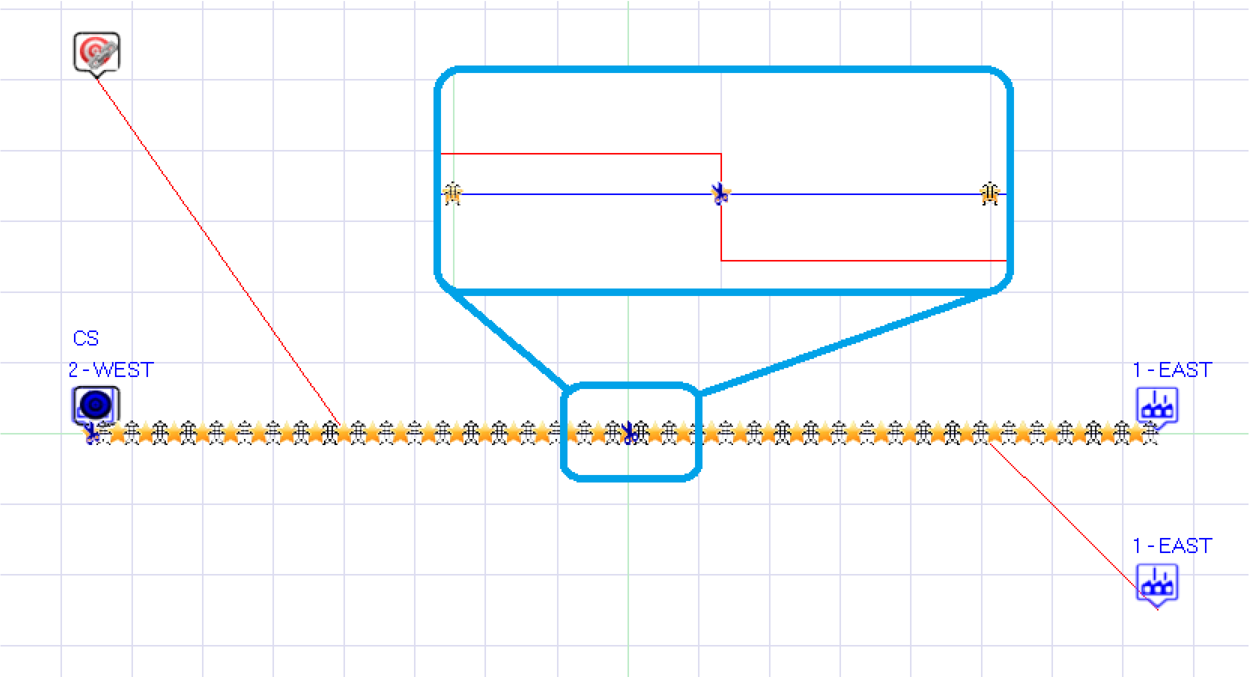


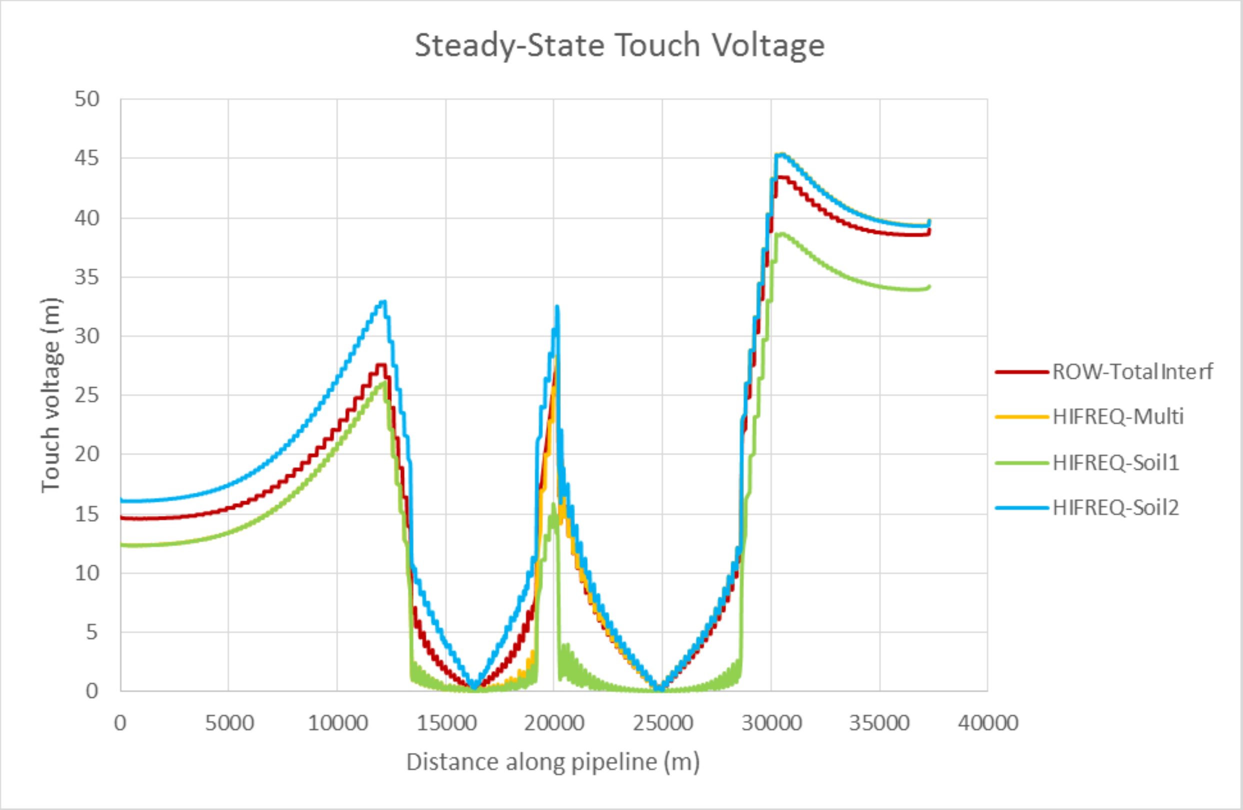
Figure 6: The system under study including one transmission line and one pipeline.

its parallelism for another 9.9 km at a distance of 25 m, and finally exits the common corridor, as shown in Figure 6. To keep the analysis as simple as possible, only two soil models were used with the boundary located 700 m west of the crossing. The soil models used in this example are selected in order to maximize the differences due to soil effects between the two soil regions, with a very high contrast between the resistivity of the soil in contact with the mitigation zinc ribbon. This will put an extra strain on the corrections applied by ROW.

Table 2: The soil models used in the ROW/HIFREQ multi-region comparison.

	West Soil		East Soil	
	Resistivity (Ω·m)	Thickness (m)	Resistivity (Ω·m)	Thickness (m)
Top	50	5.5	890	6
Bottom	444	Infinite	133	Infinite

The soil models used are presented in Table 2. As a first verification, unmitigated steady-state models were built in both software to confirm that results were similar. Excellent agreement was obtained, as could be expected since conduction plays a very limited role in the unmitigated case. The mitigation zinc ribbon was then added in two long segments, one in each soil region to ensure conductive effects play an important role in each soil region.



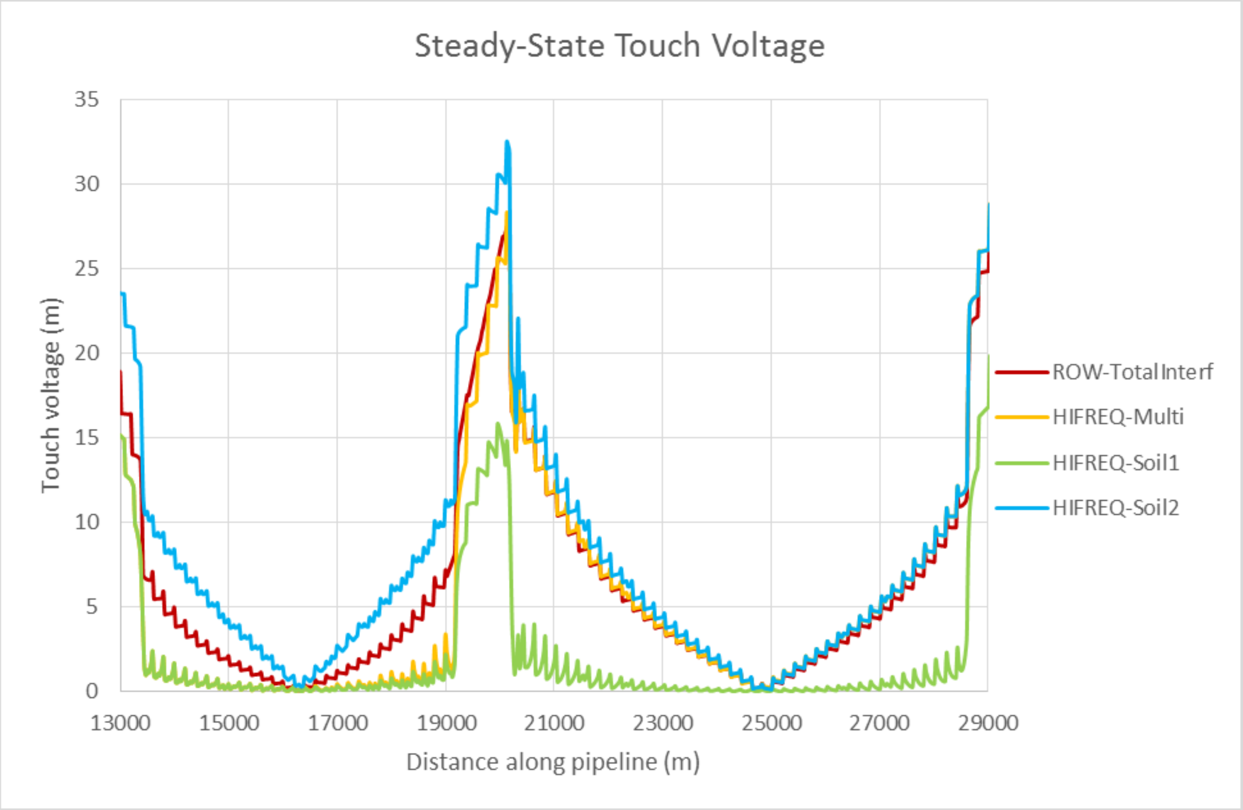


Figure 7: Results obtained for the mitigated steady-state case for the HIFREQ multi-region approach and for the Right-of-Way total interference model. The second plot focuses on the parallel portion.

This was compared to the Right-of-Way equivalent using the steady-state Total Interference results, with the conductor impedance correction applied to the mitigation phase. The agreement between the two computation approaches is almost perfect, as shown in Figure 7. For reference, the results obtained with both soil models (treated as single-region soils) in HIFREQ are presented. Finally, two fault locations were modelled, one for each soil region. The faults are located approximately in the middle of the parallel portion of each soil region.

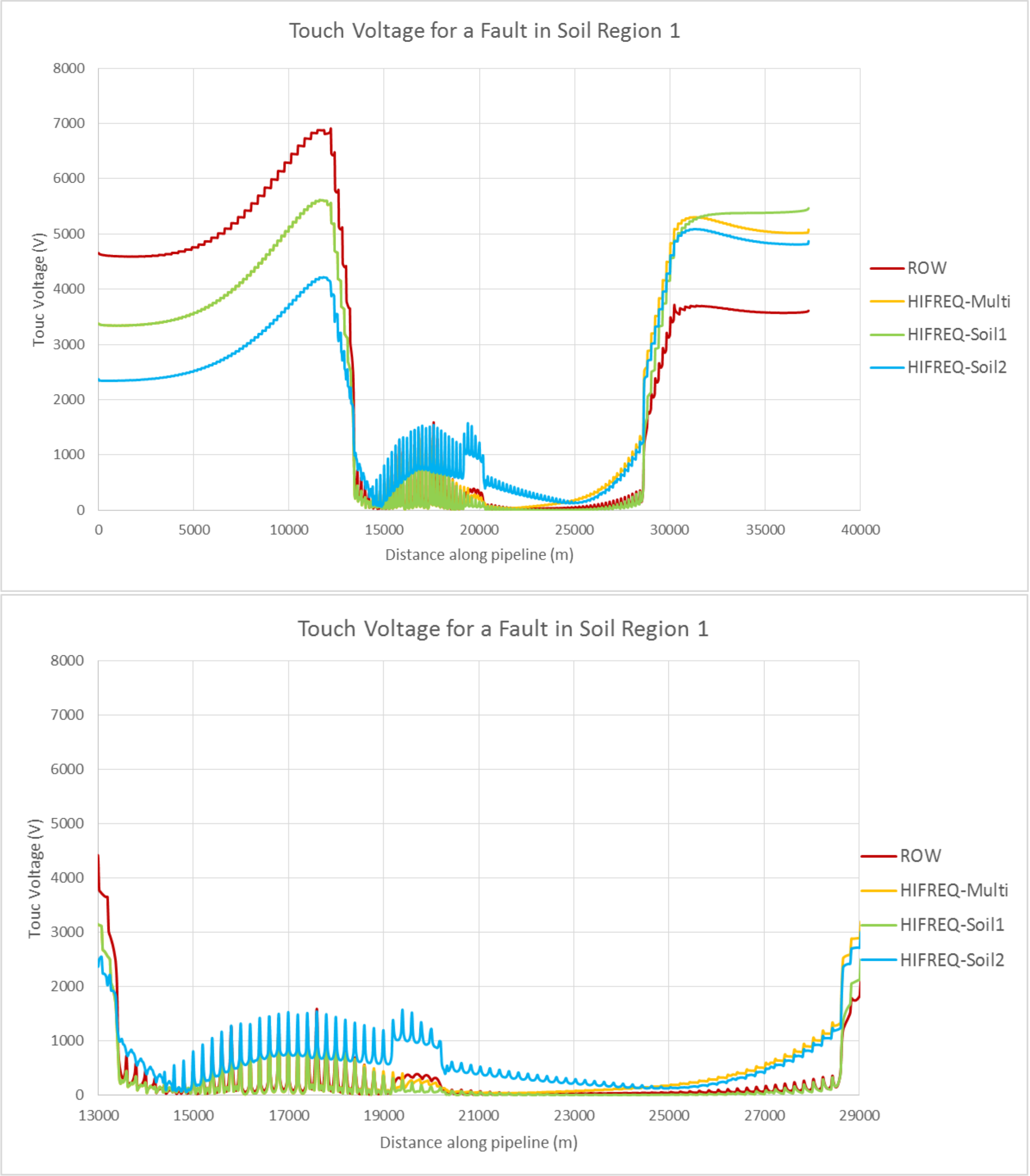
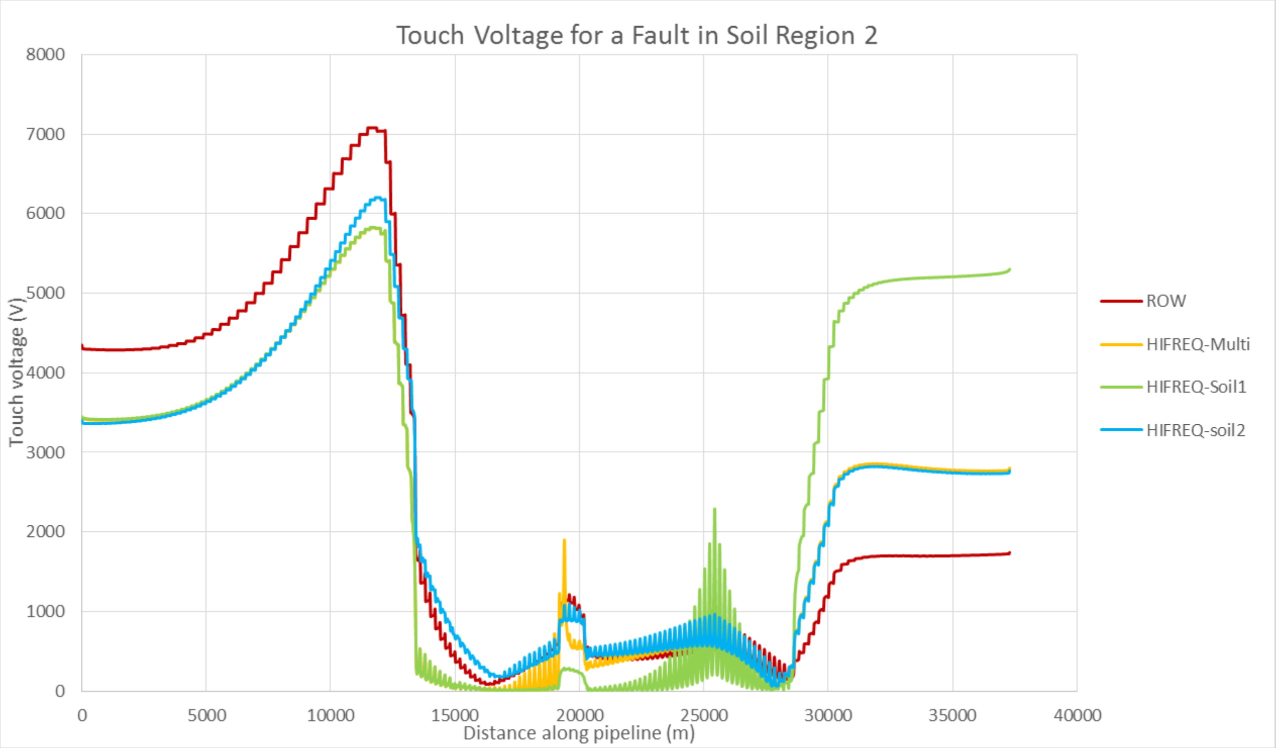


Figure 8: Pipeline touch voltage for a fault in soil region 1.

The results presented in Figure 8 and Figure 9 show some variations which will need to be analysed further before judging the validity of the proposed approach. One thing that can be observed is that the HIFREQ multi-region solution converges toward both single soil HIFREQ results far from the soil boundary. This supports the validity of the results since the effect of a soil region is expected to diminish as we get further away from it.



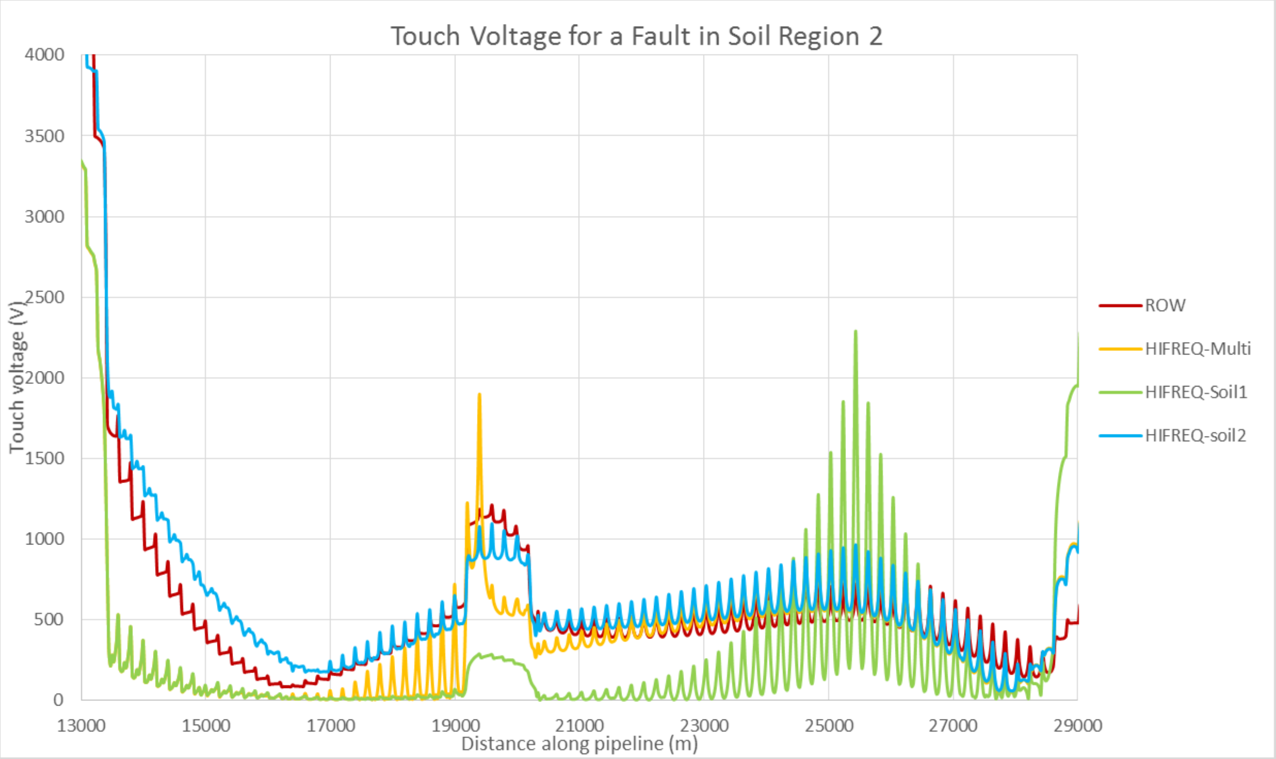


Figure 9: Pipeline touch voltage for a fault in soil region 2.

5 Conclusion

A new computational methodology to account for multiple multilayer soil models in a single HIFREQ model was presented. The results obtained with this algorithm were validated first by comparing with a MALZ vertical soil model, showing excellent agreement for uniform soil regions. A second set of validations was performed using a more complex system involving a transmission line and a pipeline sharing a common corridor, for which the results obtained with the new approach were compared with those obtained with Right-of-Way. The steady-state mitigated case results showed almost perfect agreement between these two very different computation approaches. Results from mitigated fault cases showed some differences that may be explained by the correction mechanisms to account for different soil structures in ROW, which were pushed to their limits by the very sharp contrast in soil resistivity between to two modelled soil regions. Further analysis will be performed to investigate and explain the sources of these discrepancies.

6 References

[1] S. Fortin, "Lateral Variation of Soil Resistivity – The Multi-Region Soil," in *CDEGS' Users Group Conference*, Houston, 2006.

[2] M. Daigle, F. Dawalibi, R. El Hani, S. Fortin and C. Voyer, "Progress on Implementing Simplified Multi-Region Soil Models in MALZ," in *CDEGS' Users Group Conference*, San Diego, 2015.