Geomagnetic induced currents in south-western Iberia

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Abstract

Geomagnetic storms induce electric fields along power lines, which are the source of GICs observed at high latitudes. However, there have been accounts of GICs at mid-latitudes. For this reason, countries such as Spain, Italy and Brazil are evaluating the impact of GICs in their territory. Portugal is also giving its first steps in this field. MAG-GIC is a project funded by the Portuguese Science Foundation (FCT) aiming to assess the potential hazard of GICs on the national high voltage power grid. This project involves a collaboration with REN - the Portuguese power distribution company.

In this presentation, we show how to evaluate the geoelectric fields generated in the Portuguese mainland during some of the strongest geomagnetic storms recorded at University of Coimbra's geomagnetic observatory (IAGA code: COI) during solar cycle 24. This analysis takes into account impedance matrices computed considering local magnetotelluric (MT) observations. The geomagnetic observations are complemented with simulations from the Tsyganenko-Sitnov TS04 model, which can separate the contribution of different magnetospheric current systems, giving a better insight of the phenomena involved. Additionally, we provide our first estimations of the expected GIC values based on the real distributions of transformer stations located across the Portuguese South-West (the region with the sparsest distribution of transformer stations).

1. Introduction

Geomagnetic field disturbances (B) and ground resistivities play a key role in the generation of the GICs driving electric fields (E). As is known since Tikhonov (1950) and Cagniard (1953), the 1D induced field can be expressed:

$$E_{X,Y}(\omega) = (1/\mu_0)\mathcal{Z}(\omega) \times B_{Y,X}(\omega),$$

where $\mathcal{Z}(\omega)$ is the MT impedance of the Earth.
Compared to the 50Hz high voltage AC current, GICs behave like a quasi-direct current. Thus the computation of GICs can be reduced to solving an electric circuit problem, using Kirchhoff laws (Lehtinen & Pirjola's,1985):

$$\mathbf{GIC} = (\mathbf{1} + \mathbf{YZ})^{-1}\mathbf{J}$$

where $\mathbf{1}$ is the identity matrix, $\mathbf{Y}$ the network admittance matrix and $\mathbf{Z}$ the earthing impedance matrix. The "perfect-earthing" currents generated along a grounded conductor ($\mathbf{J}$) are computed from the integration of the electric field along its path.

2. Resistivity model

To compute $\mathcal{Z}(\omega)$, we will use MT results by Santos et al. (2003) and bathymetric data of the Portuguese coast (see fig. 1) as input for the 3D ModEM algorithm (Kelbert et al. 2014). As a first approach, a simplified 1D conductivity model (see fig. 2, left) and the DigitalEarthLab.com MT algorithm have been used, to obtain an estimate for the apparent resistivity ($\rho_a = (1/\omega\mu_0)|\mathcal{Z}|^2$) (see fig. 2, right). This approach is not realistic, mainly because of the proximity to the ocean, and calculations will be improved using the 3D aforementioned conductivity model.

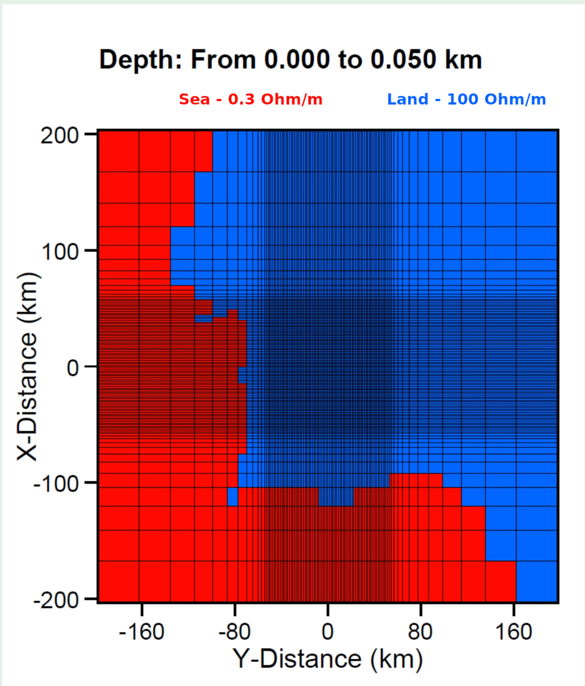

Figure 1: Horizontal discretisation of the 3D conductivity model on surface.

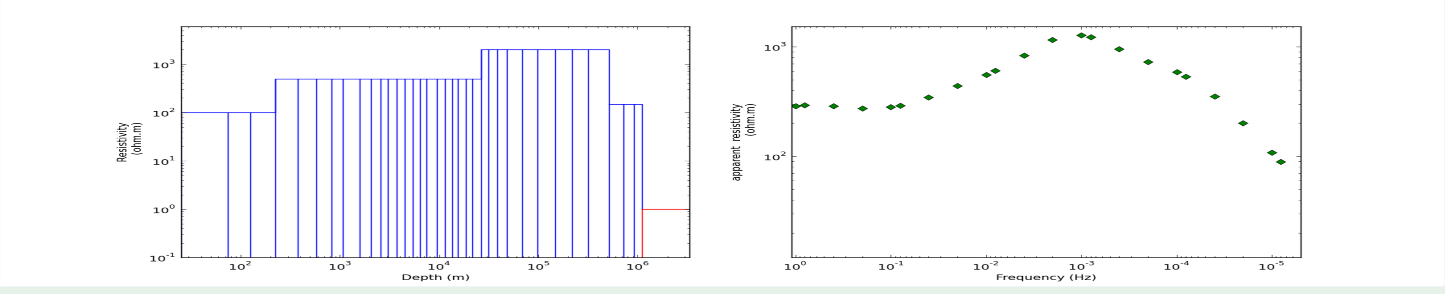

Figure 2 (left): 1D resistivity profile. (right): apparent resistivity for different frequencies of the driving field.

3. Geoelectric field

Given the small size of Portugal mainland and overall proximity to Coimbra, the geomagnetic variations recorded at the COI observatory are well suited to characterise the geoelectric fields induced in the south of Portugal. Figure 3 shows the geomagnetic variations during the March 2015 St. Patrick's Day storm, and the induced geoelectric field taking into account the 1D resistivity model in Figure 2. Red curves show the field predicted by the magnetospheric semi-empirical model from Tsyganenko & Sitnov (2005).

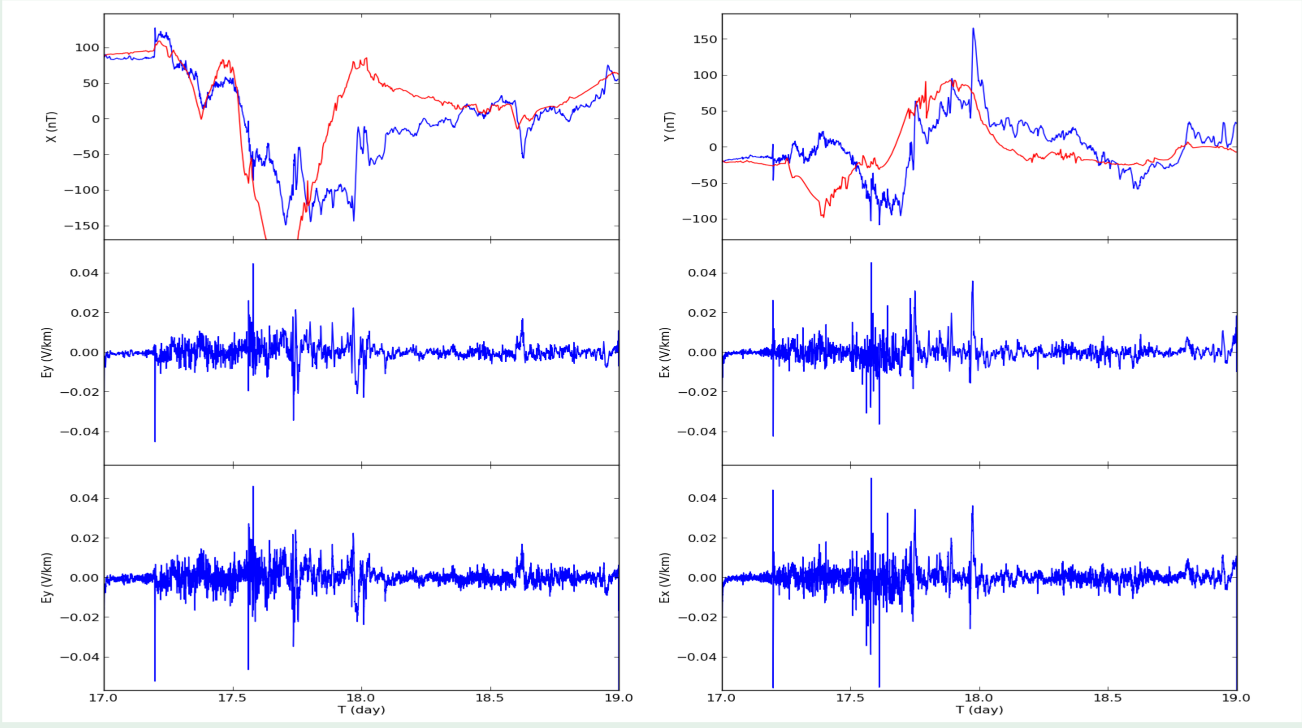

Figure 3 (top): $\mathbf{B}(t)$ *at COI observatory (blue) and TS05 model simulation (red) during St. Patrick' Day storm (March 2015); (middle): expected* $\mathbf{E}(t)$*, using 1-minute sampling time; (bottom): expected* $\mathbf{E}(t)$*, using 1-second sampling time.*

4. Power network model

The information required to characterise the Portuguese high voltage power network was provided by REN (Redes Energéticas Nacionais, SGPS, S.A.). We started by analysing a sub-grid consisting of the power network to the south of Palmela (SPM station in the upper left corner of Fig. 4), which involves only 400 kV and 150 kV lines.
The earthing impedance and resistivity matrices, as well as the current vector, were computed using GEOMAGICA Python script (Bailey, 2017) based on C. Beggan's adaptation of K. Turnbull´s algorithm.

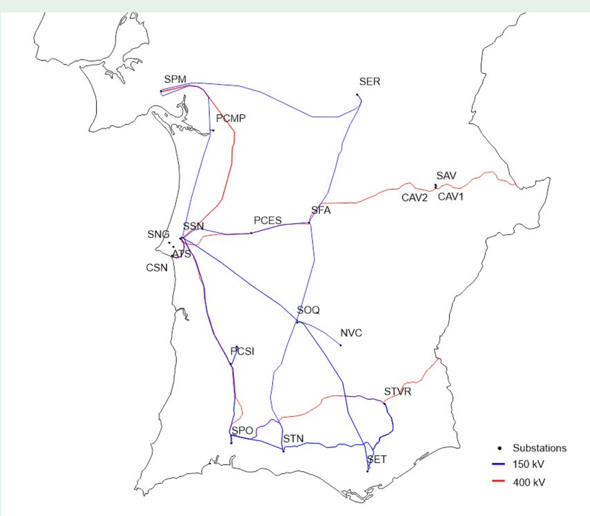

Figure 4: Southern Portuguese high voltage power network.

5. Preliminary GIC model

Our model was tested against Horton's (2012) benchmark. Figure 5 shows the GIC amplitudes generated at each transformer station, assuming normalised geoelectric fields of 1V/km in the North-South and East-West directions.
Results for SPM, SER, SAV, STVR are unreliable, as these stations are connected to other nodes not included in the calculations (substations further north and/or connected to substations in Spain).
Portimão substation (SPO) seems to be the most susceptible to GICs, which makes it the right candidate for connecting a GIC sensor to test our model (see poster p11 in this session).

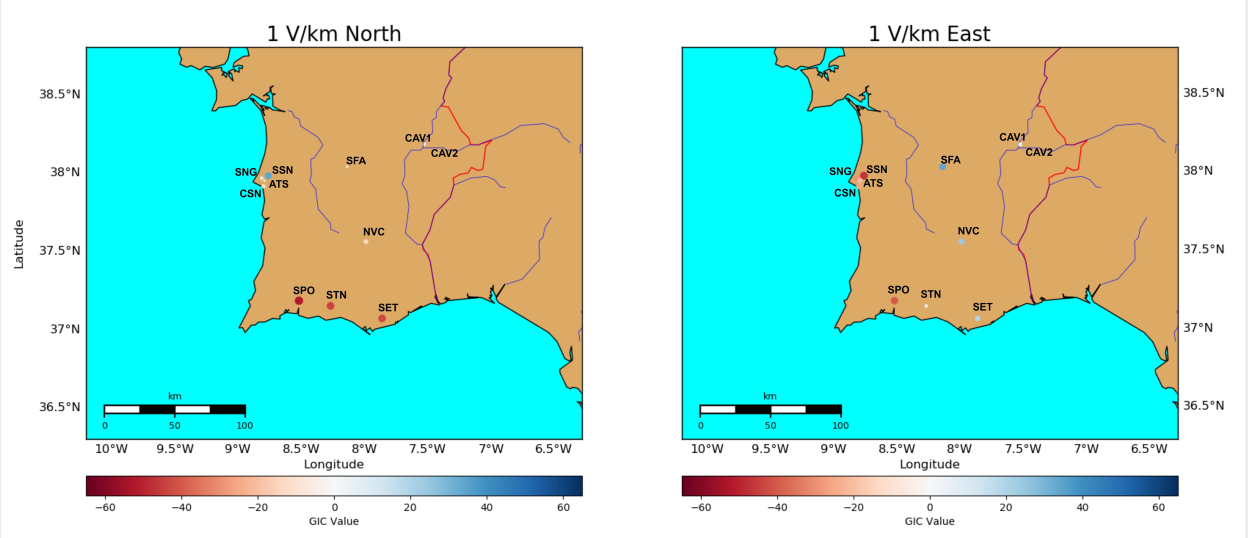

Figure 5: GIC amplitude at each transformer substation generated by a 1V/km induced $\mathbf{E}$ *field in the North-South and East-West directions.*

6. Sensitivity to network parameters

Values for grounding resistances at substations are necessary for GIC calculations. We verified that using the true values provided by REN brings significant changes to GICs, at some substations (fig. 6).

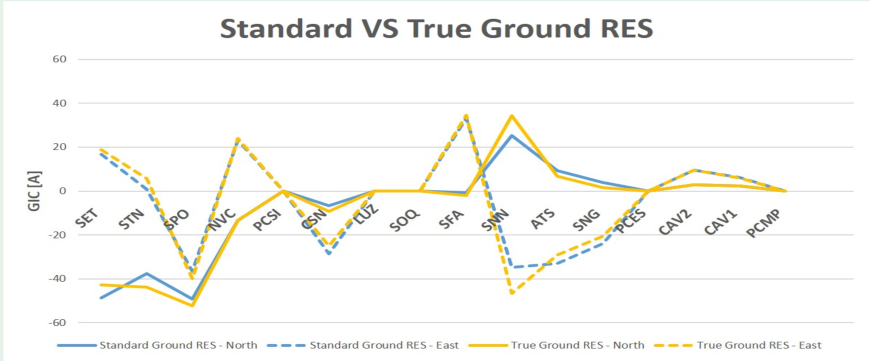

Figure 6 : GICs, using for the grounding resistance the default 0.2 Ω (blue) or the true grounding resistance provided by REN (orange).

Shunt reactors are used to control the voltage in the power network. To the south of Palmela, there are two of them: Portimão and Tavira. Taking into account their resistances did not cause a significant variation of the GIC intensity (less that 1%).

7. GIC during St. Patrick's Day storm

Figure 7 shows the GIC amplitude at the Neves-Corvo (NVC) station during the St. Patrick's Day storm.

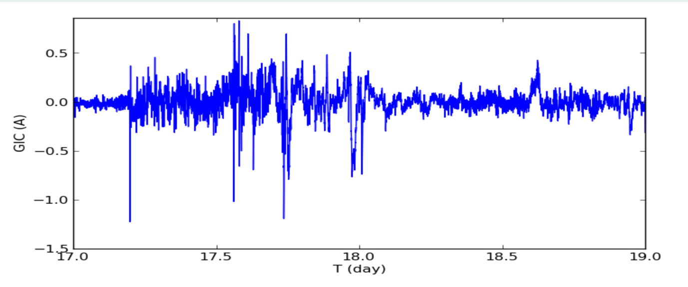

Figure 7: GIC at the Neves-Corvo power transformer during the St. Patrick's Day storm (computed using 1-second sampled data and assuming a 1D conductivity model).

8. Conclusions

- We present the first GIC simulations for the South of Portugal, using data from the national high voltage power network.
- We evaluate the impact of some electric network parameters on the intensity of GICs.
- From the subset of transformer substations that were evaluated, Portimão seems the most sensible to storms. This makes it a good candidate for GIC local monitoring.
- Further tests will be conducted, with a more realistic 3D conductivity model.

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