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Numerical modeling of geomagnetically induced currents in a Brazilian transmission line

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Abstract

Rapid changes in the external geomagnetic field induce electric currents in conducting materials at the Earth's surface. These geomagnetically induced currents (GIC) are mostly studied in transmission lines at high-latitude due to their frequent hazards. However, recent studies have shown that low- and middle-latitude regions may also be subject to problems due to GIC occurrences. In this work we apply a numerical model, using plane wave theory and a one-dimensional electrical resistivity model of the region, to calculate the geoelectric field and the GIC measured directly at the Itumbiara–São Simão (IS) transmission line (Southeast Brazil) during a magnetic storm occurred between 7–10th November 2004. We use two electrical resistivity models: (a) one-layer model, in which our results do not reproduce the measured GIC directly in the IS transmission line, and (b) four-layer model, which presents similar patterns of temporal variation and intensities of the measured electric fields and GIC. After validating the four-layer numerical model, we calculate the electric fields and GIC during the "Halloween storm" (29th October–1st November 2003). Our results of the Halloween storm show maximum GIC amplitudes of 25 A, which are higher than registered in other middle latitude countries, such as South Africa and Uruguay. These results indicate that the Brazilian power network might be subjected to the GIC hazards in the future due to strong magnetic storms. In addition, our numerical model might be used as a potential tool for different geological sets, electrical resistivity models, transmission lines with distinct characteristics and for a range of magnetic storms intensities.

Keywords: Geomagnetically induced currents; Magnetic storms; GIC in Brazil

1. Introduction

Magnetic storms are caused by disturbances in the magnetosphere-ionosphere system, as result of solar activity. Rapid changes in the external geomagnetic field induce electric currents in conducting materials at the Earth's surface (Pirjola, 2007; 2009). These currents are termed as "geomagnetically induced currents" (GIC) and propagate in electric power transmission grids, pipelines, telecommunication cables and railway systems. The understanding of GIC effects for different space weather conditions and risk analysis has been concern and debate in the scientific community (e.g. Thomson et al., 2010; Pulkkinen et al., 2012; Ngwira et al., 2013), especially due to our increasing dependence on electricity and communication systems. The well-known power failure in the Hydro-Quebec system in March 1989, for example, affected human installations over a period of about 9 h (Bolduc, 2002).

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The modeling of GIC in power networks help us to understand the GIC physical processes and can be useful to identify regions more likely to suffer such hazards. GIC calculation requires a model of electrical resistivity in the region of study, direct measurements or model of the geomagnetic field and computation of the geoelectric field and network model of the power grid (e.g. Boteler and Pirjola, 1998; Pirjola, 2000; Pirjola, 2002; Beggan et al., 2013). High-voltage power systems are more vulnerable to GIC flows, especially where they offer low resistance for the electrical current compared to the ground (Radasky, 2011; Beggan et al. 2013).

GIC are usually larger in high latitudes since auroral regions induce large east–west electric fields at the Earth's surface, amplifying these currents in more than 100 A. That is the reason why effects of space weather disturbances on high latitudes are more frequently explored (e.g. Beamish et al., 2002; Pirjola, 2005; Eroshenko et al., 2010; Beggan et al., 2013). However, there has been a growing perception that GIC might also affect technological systems in low latitude regions (Ogunade, 1986; Oselha and Favetto, 2000). Therefore, GIC have been recently measured and/or modeled in middle- and low-latitude countries such as Brazil (Trivedi et al., 2007), South Africa (Bernhardi et al., 2008), China (Liu et al., 2009), Japan (Watari et al., 2009), Spain (Torta et al., 2012), North America (Wei et al., 2013) and Uruguay (Caraballo et al., 2013).

The scarce number of observations of GIC in Brazil did not allow recognizing eventual problems caused in power grids. Trivedi et al. (2007) measured GIC in an electrical transmission line for the first time in Brazil. They registered GIC ranging from 15 to 20 A during the 7–10th November 2004 magnetic storm. However, GIC modeling and evaluation due to severe magnetic storms are not completely understood in Brazil. For example, GIC phenomena depends on the several characteristics of the transmission line (length, linear resistance, earthing resistance, etc.) and on the geoelectric structure of the regions of study. These parameters are crucial for GIC modeling and prediction. In addition, the presence of the South Atlantic Magnetic Anomaly (SAMA) in Brazil is another unknown influence. SAMA is characterized by the lowest total field intensity at the Earth's surface (e.g. Olson and Amit, 2006; Hartmann and Pacca, 2009). The influence of SAMA area coincides with a region in space of intensive radiation close to the Earth, which is attributed to the entrance of high-energy particles in the magnetosphere (e.g. Heynderickx, 1996; Heirtzler, 2002). Trivedi et al. (2005) credited larger amplitudes of the magnetic horizontal component to the increase of electron precipitation in the SAMA region, which might affect the GIC amplitudes.

In this work, we applied a numerical model to calculate the geoelectric and the corresponding GIC in a transmission line where there are records of GIC measured by Trivedi et al. (2007). We used Vassouras magnetic observatory (VSS) data, which is the closest observatory to the region of interest. We applied the plane wave model (Pirjola, 1982) to calculate the geoelectric field and an electrical resistivity model proposed by Bologna et al. (2001). The same numerical model was also used to calculate the GIC during the Halloween storm from 29th October until 1st November 2003.

This paper is organized as follows: in section 2 we present the model parameters including the location and length of the transmission line, the resistivity model, and the VSS dataset. Section 3 describes the numerical model, the calculation of the geoelectric field and the GICs. Our results are discussed in the section 4 and section 5 presents the concluding remarks.

2. Model parameters and dataset

According to the National Brazilian Electric System Operator (ONS), the transmission lines voltages range from 138 kV to 750 kV and they have lengths varying from 100 km and 2500 km, which cover the whole country (Fig. 1a). This large power network may be vulnerable to GIC hazards. Trivedi et al. (2007), in cooperation with FURNAS (a Brazilian electric company), measured for the first time GIC in Brazil. They have continuously monitored two transmission lines, from August 2004 to September 2005. The transmission lines are called "Itumbiara–São Simão" (IS) and "Pimenta–Barreiro" (PB) and they have total lengths of 150 and 200 km, respectively. The transmission lines are located between latitudes 18.5° S and 21.5° S and longitudes 44° W and 50.5° W (western of Minas Gerais State, as shown in Fig. 1b). The voltage of these transmission lines is 500 kV and their linear resistance is 0.02 Ω/km. The Brazilian electricity companies obey the ANSI / IEEE 80 standards that recommend maximum earthing impedances of 1 Ω for the high-voltage substations. In our case, we assume that the earthing impedance is the sum between of earthing resistance and the transformer resistance and it has a typical value of 0.7 Ω. As both transmission lines have similar electrical characteristics, we have considered only the IS transmission line to calculate GIC. IS transmission line is located between latitudes 19° S and 18.4° S and longitudes 50.5° W and 49.1° W and its total line resistance is 3 Ω. In this study, GIC in the IS transmission line were computed from two different magnetic storms occurred in: (1) 7th until 10th November 2004, for comparison with the GIC measured by Trivedi et al. (2007) and (2) 29th October until 1st November 2003 (Halloween storm).

Vassouras (VSS, Latitude 22.4° S, Longitude 43.6° W) is the closest magnetic observatory from the IS transmission line. This distance, of about 740 km, is considered reasonable to use VSS dataset in this work since geomagnetic field morphology and time variations are not so different between VSS and IS transmission line (Trivedi et al., 2007). For this reason, we used VSS data to model GIC for the two strong magnetic storms.