Geomagnetically induced currents – GIC in electric power system at low latitudes in Brazil: A case study

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Abstract

Geomagnetically induced currents (GIC) are a ground end manifestation of space weather processes. During the large geomagnetic storms the GIC end up flowing between the ground points of the power transformers and the electric power transmission lines connecting the transformers. In the high latitude regions damages to the power transformers are reported where the range of the storm time geomagnetic variations is very large and hence the large GIC compared to the range of variations observed at low latitudes. However GIC damages to the power transformers are a complex process it needs careful evalution even at the low latitude regions in Brazil. We report here a first such study conducted under a cooperative project between FURNAS and INPE.

Introduction

The Sun emits continuously solar plasma and engulfs the entire solar system with the plasma. The interaction of solar plasma with the Earth magnetic field affects the physical processes in the magnetosphere, the ionosphere and its net result is recorded on the Earths surface as variations of geomagnetic and geoelectric fields. Geomagnetically induced currents (GIC) are a ground end manifestation of space weather processes. Geomagnetic variations at the surface of the Earth induce electric currents in the crust and mantle of the Earth. The depth and strength of the induced electric field depend upon the frequency of the geomagnetic variations and the vertical distribution of conductivity in the Earth. These geomagnetically induced currents end up flowing through electrical power transmission systems as shown in Figure 1.

Full understanding of GIC needs a study of the chain of physical processes linked with space weather changes during geomagnetic storms and also the effects of the resulting geomagnetic variations on the solid Earth with a certain conductivity distribution. INPE does research work in both of these areas by conducting continuous geomagnetic measurements at several points in Brazil for studying space geophysics and conducting magnetotelluric and geomagnetic deep sounding experiments to identify conductive geologic structures in Brazil.

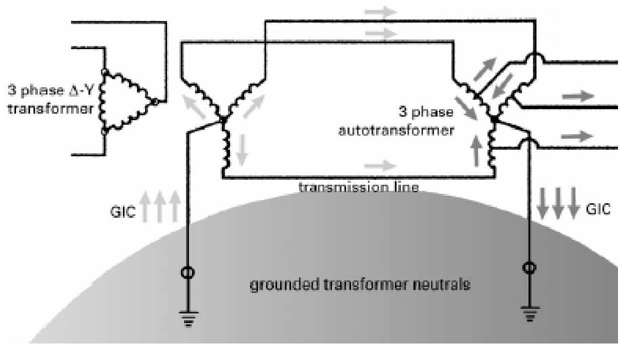

Figure 1 – Induced geoelectric field drives GIC to and from neutral ground points of power transformer. Source: Molinski (2002).

Induced geoelectric field corresponding to geomagnetic variations drive GIC currents to and from neutral ground points of power transformer. Hence GIC are known to flow in the transmission lines and windings of transformers by entering and leaving the directly earthed neutrals of high voltage star connected windings as shown in Figure 1. As the typical periodic variations of GIC fall in the range of 100 to 1000 seconds its effect on the operation of the transformer designed for 50/60 Hz is close to slowly varying direct current (GIC) flowing in the transformers. GIC currents of up to 200 Amperes are reported to flow in the transformers situated in US, Canada, Finland and Sweden when the geomagnetic storms are in progress (Kappenman 2003; Price 2002; Lahtinen and Eleovaara 2002). These occurrences saturate transformer cores and lead to various damages causing large scale power failures as reported by Pirjola (2000, 2002), and Kappenman (2003). Large geomagnetic and geoelectric variations and hence large GIC take place during geomagnetic storms in the auroral regions. It is known that GICs are a function of various other parameters like rate of variations of geomagnetic field, high electrical resistivity of the Earth crust, geometry of transmission lines and certain engineering consideration of the electrical power machinery. Hence the conventional wisdom does not always hold good for low latitude regions where GIC should be small as a rule. Yet several authors have mentioned some damage incidents due to GIC at low latitudes.

The caution advised in the literature regarding GIC at low latitudes led us to undertake a project in cooperation between FURNAS and INPE to study GIC and its effects on the power transmission lines in south eastern Brazil. This project is in progress from the first quarter of 2004.

Methodology and instrumentation

The method adopted is direct and simple as described by Pirjola (2000, 2002) and Viljanen (1998). It is planned to measure horizontal geomagnetic field variations (H and D components) directly under the power transmission lines (TL) carrying several hundred kilovolts at high current ratings of hundreds and thousands amperes and compare the results with a reference station situated at a distance of few tens of kilometers and also at the magnetic observatory at Vassouras, RJ. The geomagnetic field measured under the TL would measure the sum of the natural geomagnetic variations produced in the ionized atmosphere above the Earth and the geomagnetic field produced by a GIC flowing through the transmission lines. If one subtracted geomagnetic field variations recorded at a reference station (Vassouras) from those recorded under the TL, there would remain magnetic variations corresponding to the GIC. The strength of the GIC is calculated using the Biot-Savart law. It is also planned to measure GIC currents using a Hall current sensor, in the near future, at the neutral ground point of the transformer at a power substation to compare it with the GIC intensity derived from the geomagnetic measurements done under the TL. Three component fluxgate magnetometers to measure geomagnetic field variations (H, D, and Z components) have been constructed at INPE (Kabata et al. 2003, and Trivedi et al. 1995). A GIC current measuring instrument based on Hall sensor has being constructed at INPE and is being presently tested Itumbiara substation of FURNAS.

The equation of Biot-Savart law is given by

$$B = \frac{\mu I}{2\pi r} \quad \therefore \quad I_{GIC}(A) = \frac{B(nT)\, r(m)}{200}$$

where B is the magnetic field in nanotesla obtained by the operation $B = \mathrm{TL}(H) - \mathrm{VASSOURASS}(H)$ is. the difference between the measured H under the TL minus the measured H at the observatory of Vassouras, the symbol I is for (GIC) current in ampere to be calculated, r (m) is the distance of the magnetometer from the cable of TL in meter and μ is the permeability of air ($\mu = 400\pi$ nH·m^{-1}).

Selection of the site

In Table 1 are listed the places suggested by FURNAS, where the geomagnetic field measurements for deriving GIC could be conducted. The electric power transmission line of FURNAS between the cities of Itumbiara in the state of Goiás, GO, and São Simão in the state of Minas Gerais, MG, was selected for conducting geomagnetic measurements underneath the TL at Itumbiara. Another electric power transmission line between Pimenta and Barreiro also in the state of Minas Gerais was selected for conducting geomagnetic measurements under the TL. These TLs are very convenient places and are shown in the Figures 2a and 2b. The magnetotelluric research group of INPE has derived a model for the distribution of electrical conductivity in the crust and upper mantle of the area lying between, the TL lines 3 and 4 listed in Table 1, that is Itumbiara–São Simão and Pimenta–Barreiro TLs. The location of MT profile is shown in Figure 3 and the conductivity model in two dimensions derived from the MT measurements is shown in Figure 4.

Table 1 : List of selected TL of FURNAS

Line	Volts	Length	Place
Araraquara–Poços de Caldas	500 kV	176 km	MG/SP
Furnas–Poços de Caldas	345 kV	131 km	MG/SP
Pimenta–Barreiro	345 kV	198 km	MG
Itumbiara–São Simão	500 kV	166 km	GO/MG

MG = Minas Gerais; SP = São Paulo

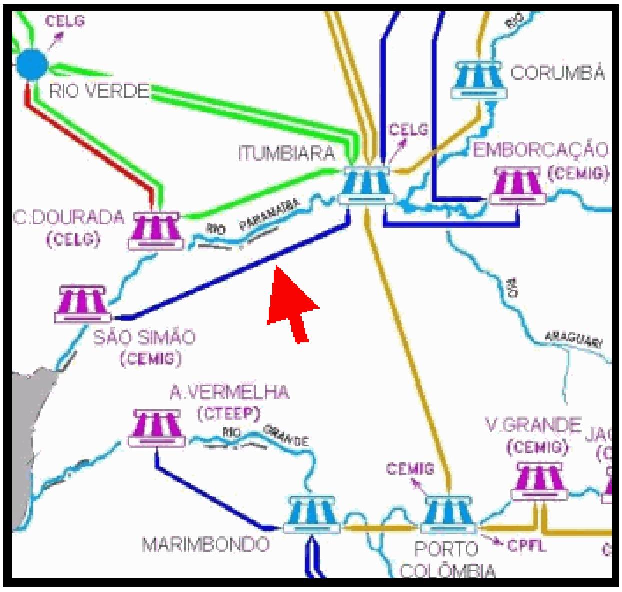

Figure 2a – TL Itumbiara–São Simão. Red arrow shows the local of magnetometer.

Measurements and results

Geomagnetic field measurements under the Itumbiara–São Simão LT and Pimenta–Barreiro LT are conducted continuously since September 2004 and the data of H, D, and *Z* variations are recorded at a sampling rate of one minute. Geomagnetic variations in the *H* component that is in the direction of magnetic meridian are the most important at low latitude stations. We treat both *H* and its orthogonal horizontal component *D* for deriving GIC but the signature of the GIC is predominant in the *H* component so as a first approximation one can ignore *D* variations. GIC are derived for every day however they appear clearly during the period of geomagnetic storm. A geomagnetic storm took place during 7 to 10 November 2004. We plot here *H* variations under both the selected transmission lines and at the magnetic observatory Vassouras. Geomagnetic signatures of GIC are obtained by subtracting *H* variations recorded at Vassouras from the *H* variations recorded under the TL. The intensity of

GIC currents are derived from the geomagnetic variations due to GIC using the formula of Biot-Savart law. The incidence of GIC at both the TLs are indicated by the arrows in Figure 5.

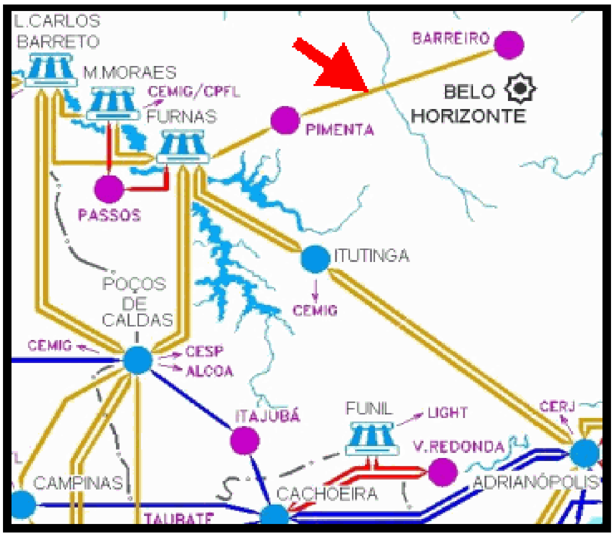

Figure 2b – TL Pimenta–Barreiro.

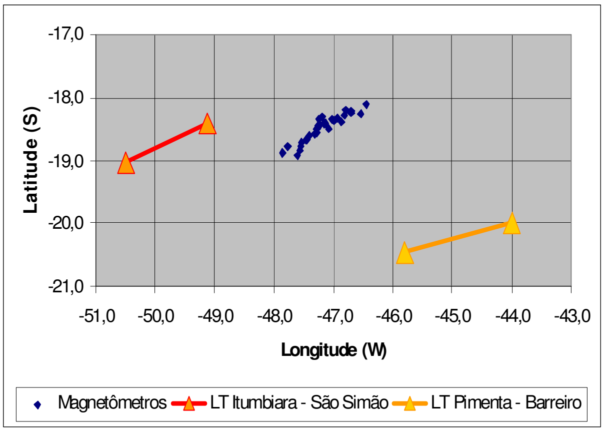

Figure 3 – Geographical locations of TL and MT profile.

The incidence of the GIC can be singled out by plotting the rate of variation of *H* field (*dH/dt*) as shown in Figures 6 and 7. This also shows that the occurrence of GIC is global, only their magnitudes could be different depending upon the magnitudes of the *variations* of horizontal field components *H* and *D*. One can see that at the Brazilian low latitudes *H* is the important component of the horizontal field in generation of GIC signal. Whereas at high latitude station like Nurmijarvi in Finland both *dH/dt* and *dD/dt* are equally important as shown in Figure 7.

Conclusions

The methodology adopted by FURNAS/INPE is promising. It is planned to conduct extensive measurements of GIC under various other TL and at the neutral points of the power transformers situated in the different regions of the country where the Earths conductivity structures could be very different.

GIC amplitudes flowing in the transmission lines of Itumbiara–São Simão and Pimenta–Barreiro region were found to be about 10 to 15 amperes during the November 2004 geomagnetic storm. At a high latitude station Nurmijarvi in Finland they were around 150 amperes about 10 times higher than observed in Brazil.

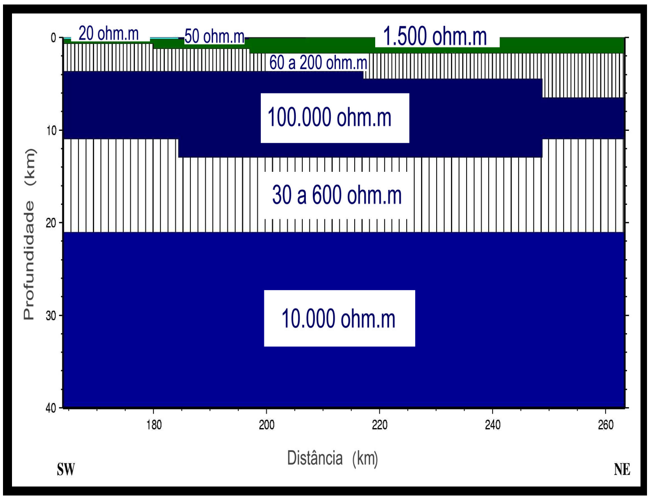

Figure 4 – Conductivity model of the area. Source: Bologna et al. 2001.

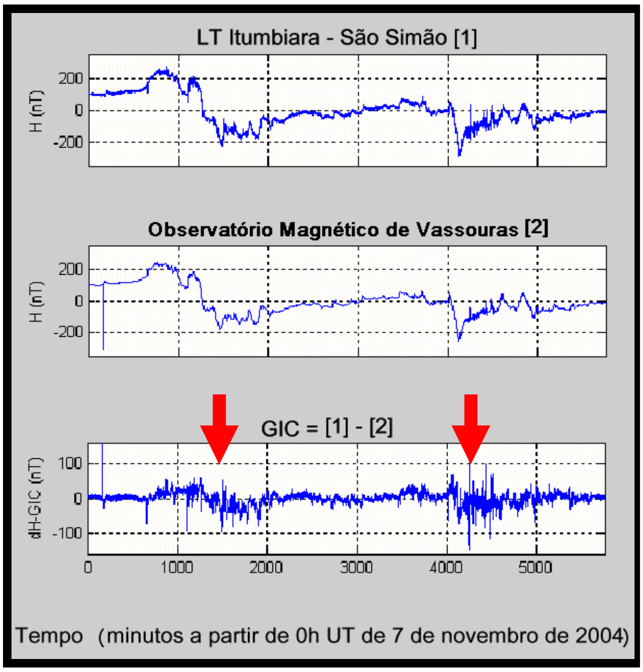

Figure 5 – The first trace (in both the diagrams) is of *H* variations under the transmission line, second trace is *H* variations at a reference station (Vassouras) and the third trace is the calculated GIC variations in the respective transmission lines.

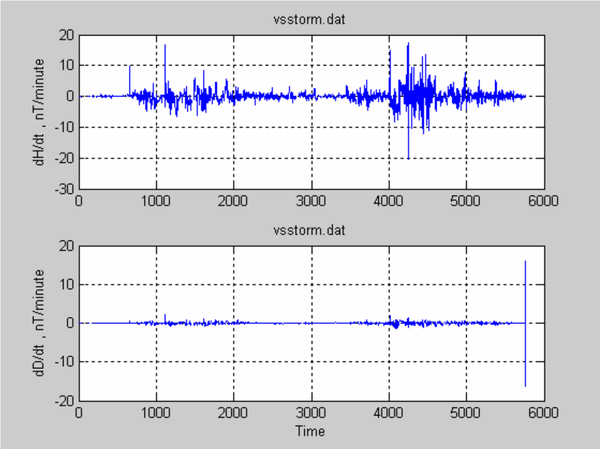

Figure 6 – Upper trace is *dH/dt* and the lower trace is for *dD/dt* for *H* and *D* variations recorded at a reference station (Vassouras). Time is in minutes starting from the zero hour of 7 November 2005.

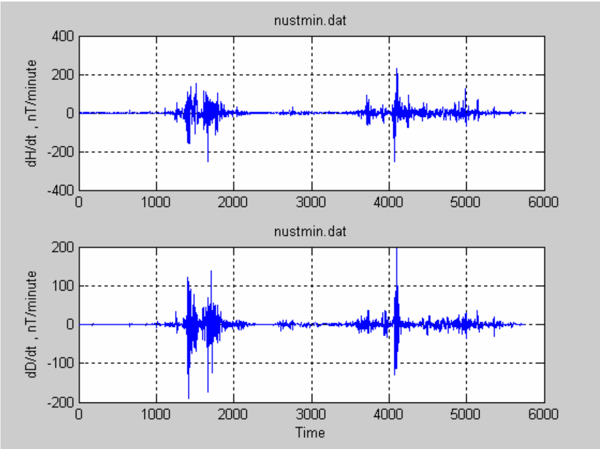

Figure 7 – Th rates *dH/dt* and *dD/dt* for the geomagnetic variations recorded at Nurmijarv in Finland during 7-10 November 2004. Time is in minutes starting from the zero hour of 7 November 2005.

Acknowledgments

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