Effects of Geomagnetically Induced Currents-GIC on Electric Power Technology in Brazil

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Abstract

Geoelectric fields induced in the Earth during geomagnetic storms drive electric currents through the windings of power transformers and the transmission lines carrying electric power. These currents, known as GIC (Geomagnetically Induced Currents), flow in the entire electric power systems and cause deleterious effects. The well-known and documented GIC events of 13-14 March 1989 and 29-30 October 2003 inflicted considerable damages and power failures in the northern auroral regions. In Brazil, there is an on-going project to study GIC in a collaborative effort between the National Institute for Space Research-INPE and Furnas Centrais Elétricas S.A. We present here the already published results on calculated intensity of GIC flowing in the transmission lines near Itumbiara in central Brazil during the event of 7-11 November 2004 and the recent progress of the work. We established a linear relationship between the rate of variation of the horizontal geomagnetic dH/dt and the calculated GIC flowing in the transmission lines near Itumbiara (Goiás). Although no significant geomagnetic storms have occurred after November 2004 we present here results from direct measurements of GIC on the neutral phase of the power transformer at the electric power substation at Itumbiara and compare the measured GIC values to the deduced GIC values flowing in the transmission lines.

Introduction

The Sun emits continuously solar plasma and engulfs the entire solar system with the plasma. The interaction of solar plasma with the Earth's magnetic field affects the physical processes in the magnetosphere and ionosphere and their net result is recorded at the Earth's surface as variations of geomagnetic and geoelectric fields. Geomagnetically induced currents (GIC) are a ground end manifestation of such 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 distribution of the conductivity in the Earth. Geomagnetically induced currents end up flowing through electrical power transmission systems as shown in Figure 1.

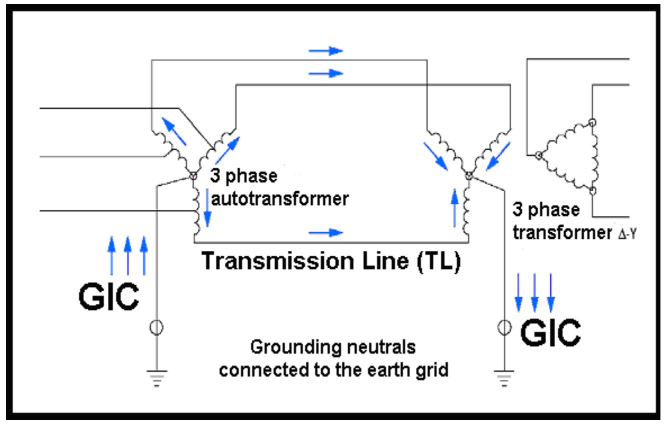

Figure 1: Schematic diagram of GIC flow in the electric power transmission System (modified version of a figure by Molinski, 2002)

The geoelectric field induced by geomagnetic variations drives GIC between directly-earthed neutral points of power transformers having a star connection and the ground (Figure 1). Hence GIC also flow through transformer windings and in transmission lines between transformers. As schematically indicated in Figure 1, GIC are equally divided between the three phase conductors. 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 that of a direct current. GIC of up to 200 amperes are reported to flow in the transformers situated in auroral regions in the USA, Canada, Finland and Sweden when geomagnetic storms are in progress (Kappenman, 2003; Price, 2002; Lahtinen and Elovaara, 2002; Pirjola et al., 2005). These occurrences saturate transformer cores and may lead to various damages possibly causing large scale power failures mentioned for example by Pirjola (2000, 2002), and Kappenman (2003). The most famous problematic GIC event so far occurred in the Hydro-Quebec power system in Canada during an intense geomagnetic storm in March 1989 (Bolduc, 2002). Large geomagnetic variations with significant geoelectric fields and hence high GIC magnitudes take place during geomagnetic storms in the auroral regions. It is known that GICs are functions of various parameters including the rate of change (i.e. the time derivative) of the geomagnetic field, the electric resistivity of the Earth, and the geometry and resistances of the power grid considered. The impacts of GIC depend on certain engineering aspects of the electrical power machinery. Hence the conventional wisdom does not always hold good for low latitude regions where GIC should be small and harmless as a rule. Based partly on some vague reports, GIC problems have obviously also occurred in power grids located in mid and low latitude areas in the past. In this respect, Poppe and Jorden (2006) give an example of a transformer in South Africa that was damaged due to GIC during the famous Halloween storm in October-November 2003. Low- and mid-latitude pipelines in Africa and South America have also experienced GIC effects (e.g. Barker and Skinner, 1980; Ogunade, 1986; Osella and Favetto, 2000).

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), Viljanen (1998) and Trivedi et al., (2007). Our experimental work so far is concentrated around the power station at Itumbiara (18.55 S, 49.23 W) and under the transmission line Itumbiara – São Simão. We measured 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.

The equation of Biot-Savart law is given by

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

where B is the magnetic field in nanotesla obtained by the operation $B = \mathrm{TL}(H) - \mathrm{VASSOURASS}(H)$, that 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 (μ = 400π nH·m^{-1}).

For geomagnetic measurements carried out 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). Also, a GIC current measuring instrument based on Hall sensor has been constructed at INPE and is being used to monitor GIC current on the neutral phase of a transformer at Itumbiara power substation of FURNAS to compare the results with the other methods.

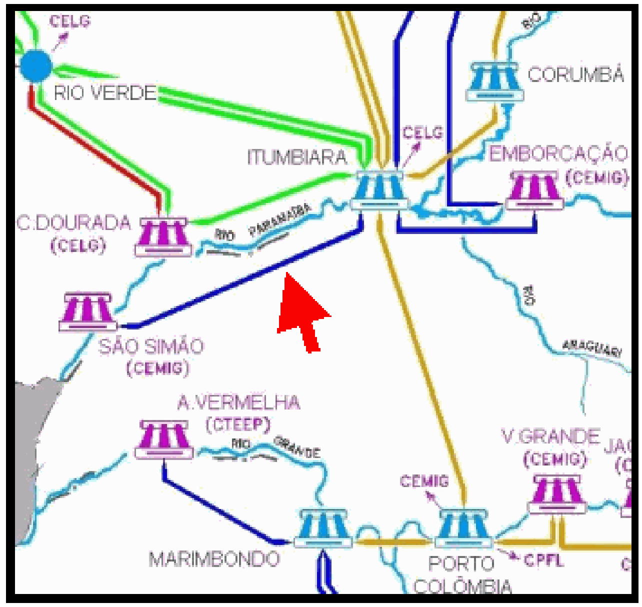

Figure 2 – TL Itumbiara – São Simão. Red arrow shows the local of magnetometer.

Measurements and results

Geomagnetic field measurements under the Itumbiara–São Simão TL are conducted continuously (however with several periods with absence of data) 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 in the Itumbiara – São Simão TL is seen as an envelope of pulsations in Figure 4.

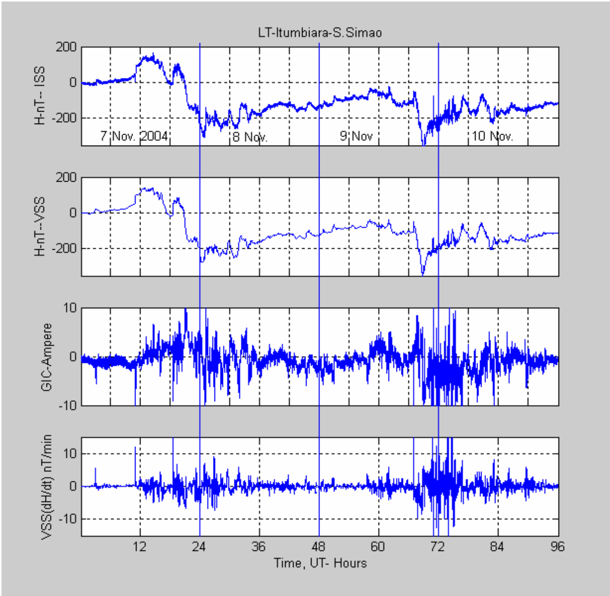

Figure 3 – The first trace is of *H* variations under the Itumbiara-São Simão (GO) transmission line and the second trace is of *H* variations at a reference station (Vassouras). The third trace is the calculated GIC variations in the transmission line and the last trace is for the time derivative of H variations at the Vassouras magnetic observatory.

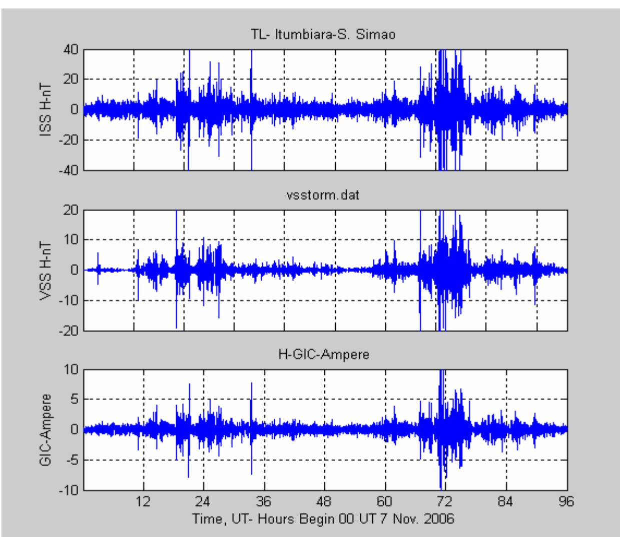

Figure 4: Same as in Figure 3 for the data obtained under Itumbiara- Sao Simão TL. However the data under the TL and at the reference station have been band pass filtered in the period range of 3 to 15 minutes.

The incidence of the GIC can be singled out by plotting the rate of variation of *H* field (*dH/dt*) as shown in Figures 3 and 4. 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 most important component of the horizontal field in the generation of the GIC signal.

Figures 3 and 4 show that 2 nT amplitude of dH/dt corresponds to almost 1 A of GIC current in the transmission lines. We may get a further knowledge of GIC from the direct GIC measurements by a Hall magnetometer fixed on the cable taking the neutral phase of the power transformer at Itumbiara substation. We present a diagrams (Figures 5 & 6) of Hall magnetometer measurements at Itumbiara and dH/dt at Vassouras. It seems that directly measured GIC is roughly one third of the calculated GIC from the geomagnetic measurements under the transmission line.

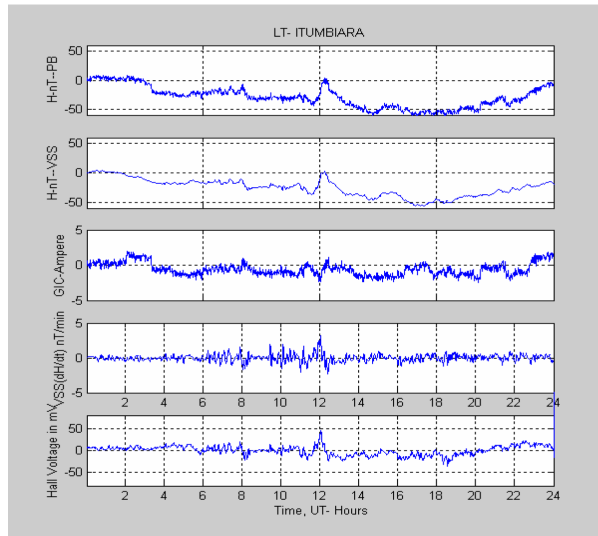

Figure 5: Traces 1 & 2 are H recordings under the transmission line and at the Vassouras magnetic observatory from 9 UT 11 July 08 to 9 UT 12 July 08. Trace 3 is the calculated GIC, trace 4 is the dH/dt at Vassouras, and the last trace is the direct measurement of GIC by Hall magnetometer.

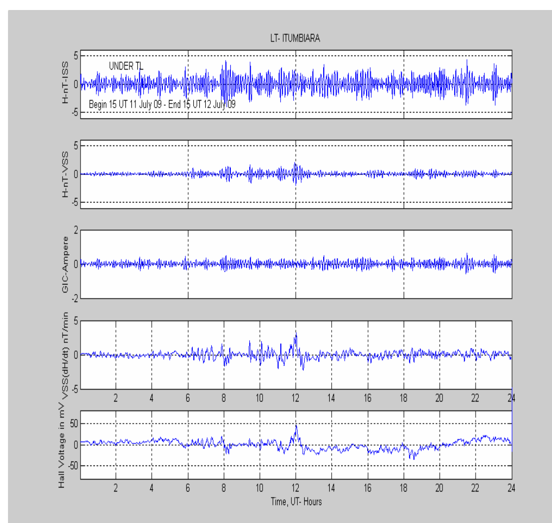

Figure 6: Same as in figure 5 but after filtering the data by a band pass filter between 3 and 15 minutes.

Conclusions

The methodology adopted by INPE/FURNAS 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 Earth conductivity structures could be very different.

GIC amplitudes flowing in the transmission lines of Itumbiara–São-Simão region were found to present a magnitude of 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.

Acknowledgments

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