Geomagnetically induced currents: The case of Kenyan electric power grid

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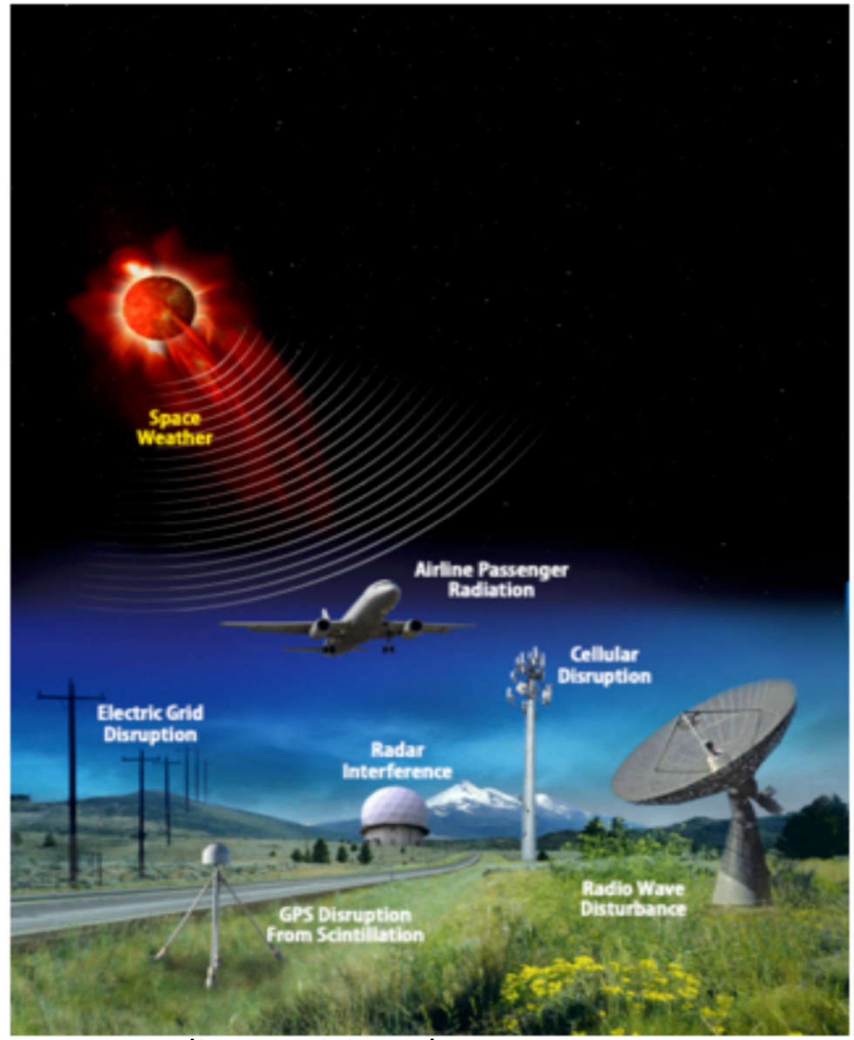
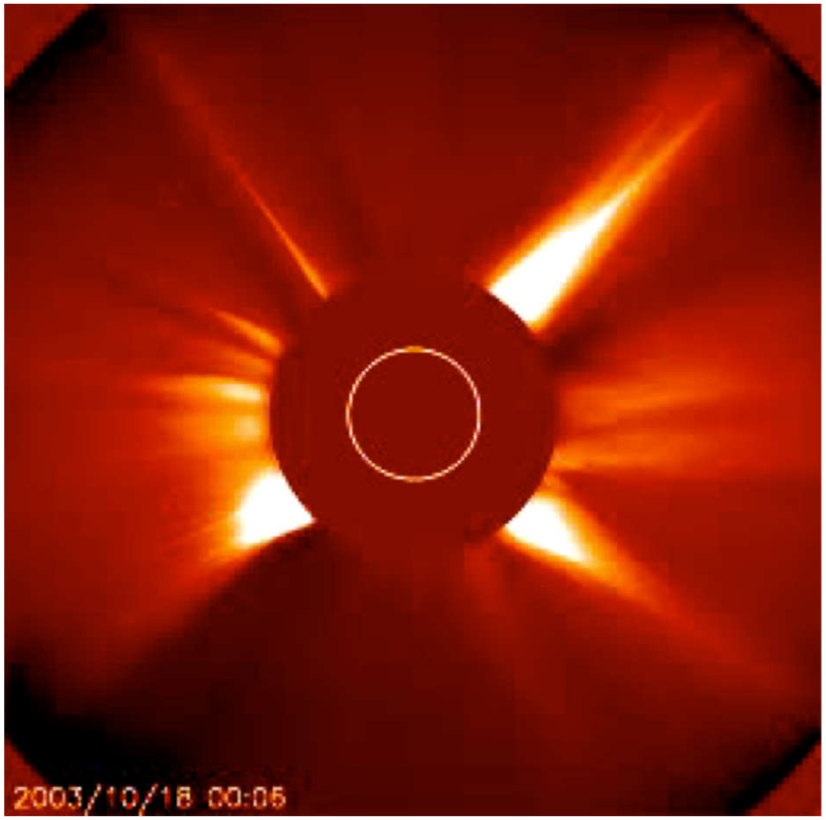


Credits: Patricia Doherty

Outline

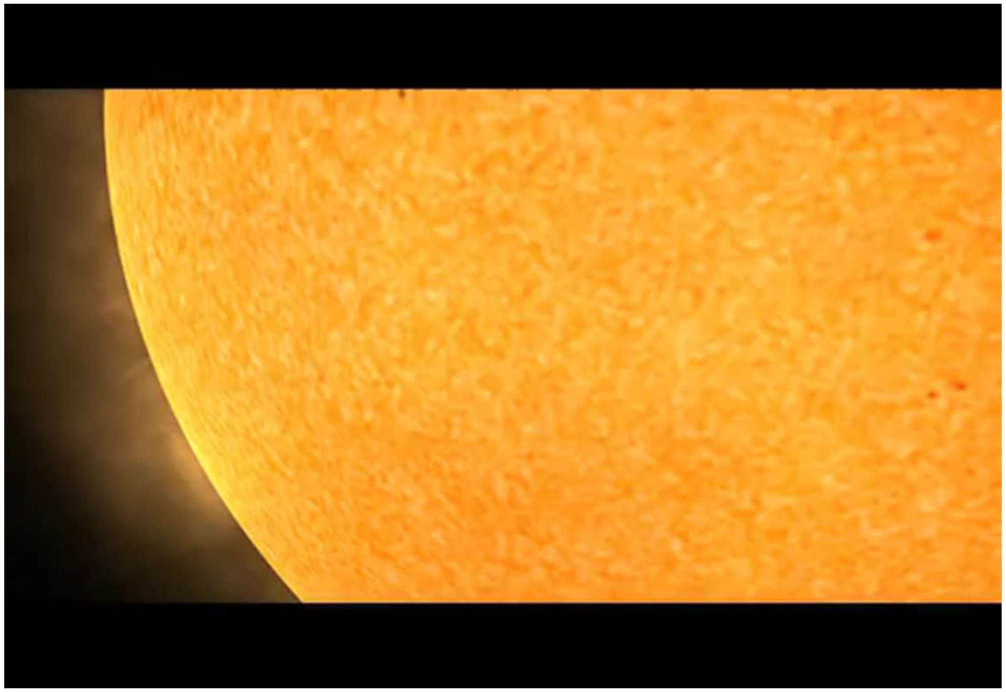
- ❑Introduction
- ❑Data and Method
- ❑Preliminary results and discussion
- ❑Conclusions and future work



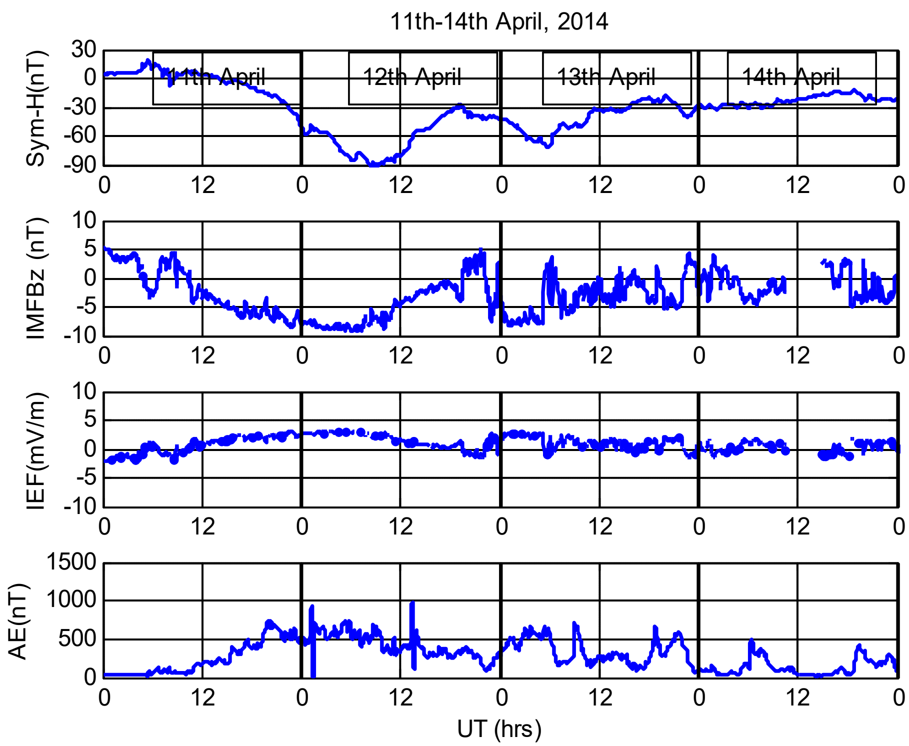
Introduction

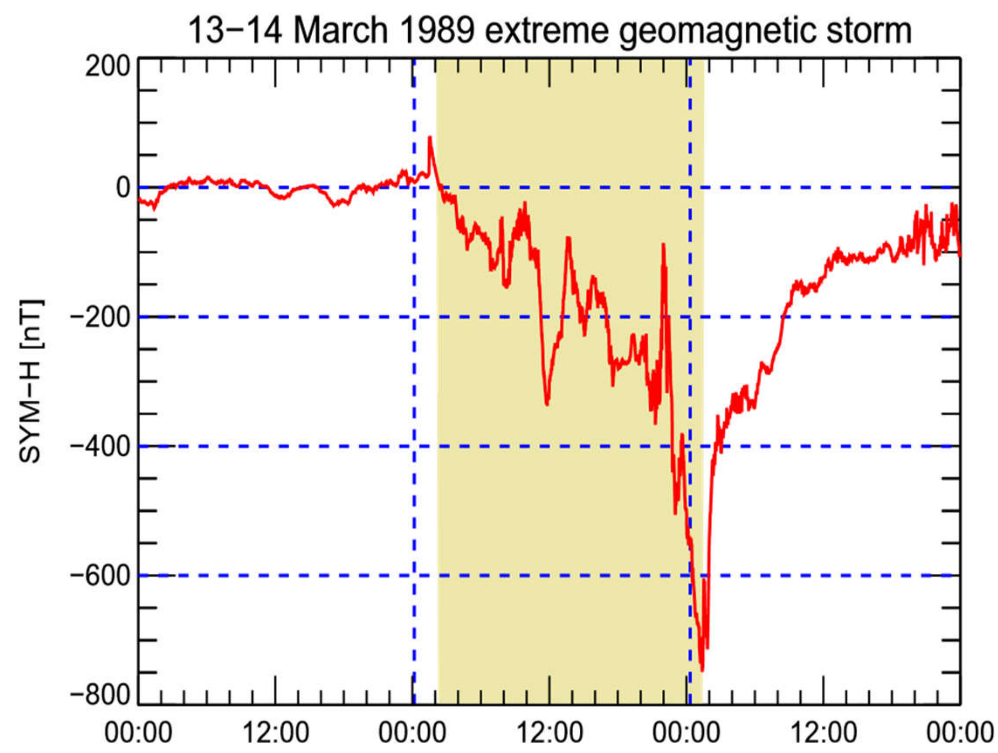
- A geomagnetic storm is a major disturbance of Earth's magnetosphere that occurs when there is **efficient exchange of energy from the solar wind into the space environment surrounding the Earth.**

- The solar wind conditions that are effective for creating geomagnetic storms are sustained (for several hours) periods of high-speed solar wind, and most importantly, **a southward directed Interplanetary Magnetic Field at the dayside of the magnetosphere**



Introduction: continuation





Introduction: geomagnetic storm Intensity strata

- NOAA Space Weather Scales

Scale	Description	Kp Values
G5	Extreme	9
G4	Severe	8, 9-
G3	Strong	7
G2	Moderate	6
G1	Minor	5

Based on Dst index (Loewe and Prolss, 1997)

Class	Dst Range (nT)
Great	< -350
Severe	$-200 \text{ to } -350$
Strong (Intense)	$-100 \text{ to } -200$
Moderate	$-50 \text{ to } -100$
Weak	$-30 \text{ to } -50$

Introduction: Motivation and Objective

- **Motivation:**

Previously GICs were considered high latitude phenomena due to the auroral activity in these regions near magnetic poles. Nevertheless studies in mid-low latitudes also revealed that GICs occur in their power networks during geomagnetic disturbances

(Ngwira, 2008)

- **Objective:**

To infer the possibility of Geomagnetically Induced Currents in the electric power grid in Nairobi, Kenya.

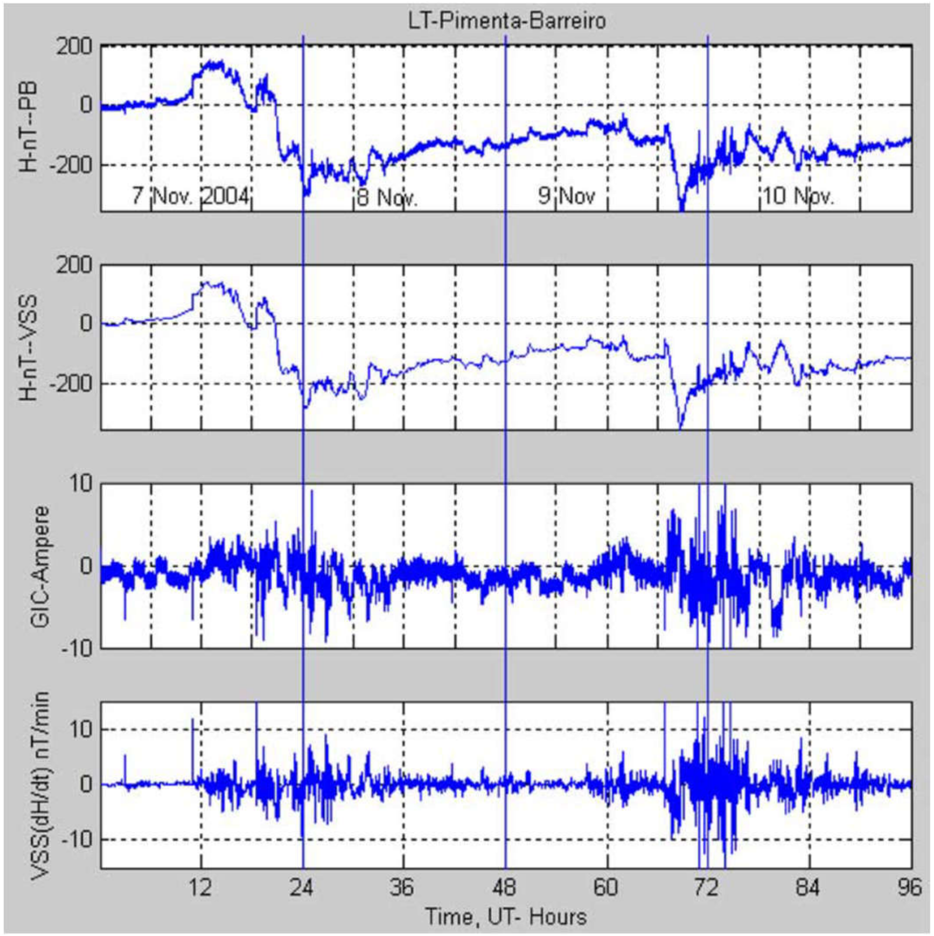
Introduction: Background

- During a geomagnetic storm, an electric field is induced on the Earth's surface according to Faraday's law of electromagnetic induction
- $\nabla \times \boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}$
- The electric field that is induced at the Earth's surface causes different areas on the ground to be at different electric potentials.

- When we consider two different grounding points of power transmission system at different locations, typically at electrical substations a current will flow from the point of higher electric potential to one of lower potential.
- The ESP that is impressed between grounded neutrals of wire-connected transformers acts as an ideal voltage source causing GICs to flow into the network system. Due to their low period which is in the order of minutes, as opposed to the AC period of transmission networks, **GICs appear as slowly varying DC.**

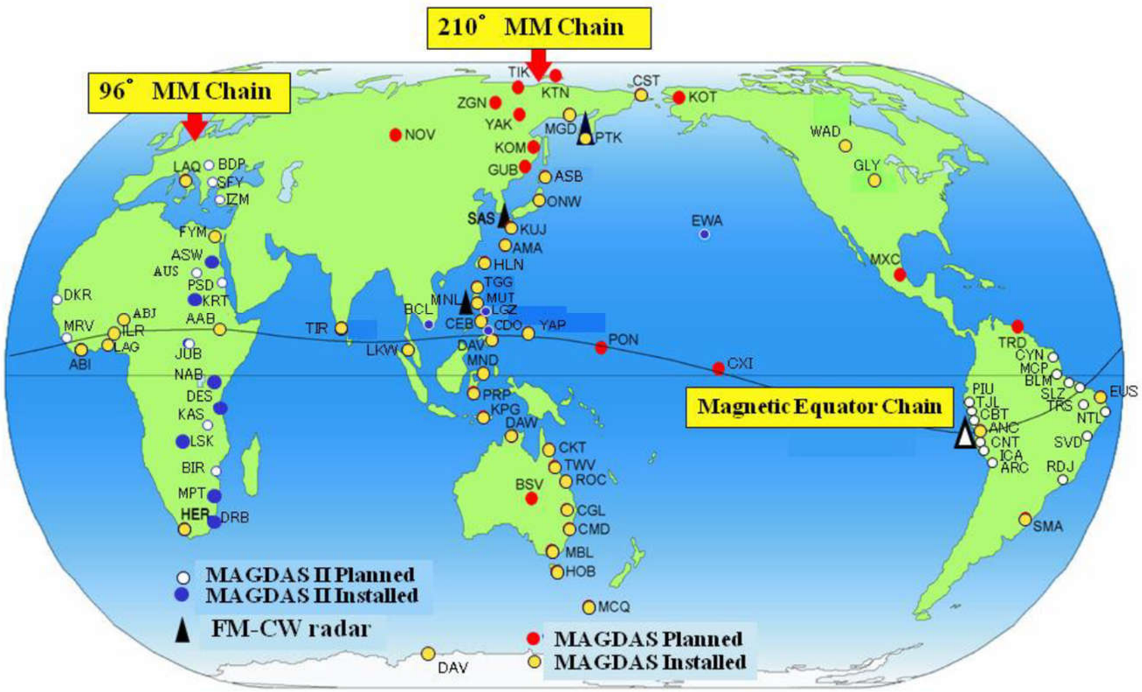
Background :continuation

- Half-cycle saturation of power transformers and reactors results in the production of harmonics, unusual swing in real reactive power flow, intense stray flux, temperature rise and gas formation, audible noise and voltage depressions.
- On 13th March, 1989, one of the severe magnetic storms sent electric currents surging through power systems in North America and northern Europe. The result was **the saturation of transformers, overload of equipment, lines tripped out of service, burn out of transformers and collapse of the Hydro-Quebec power system leaving the 6 million residents without power for 9 hours.**



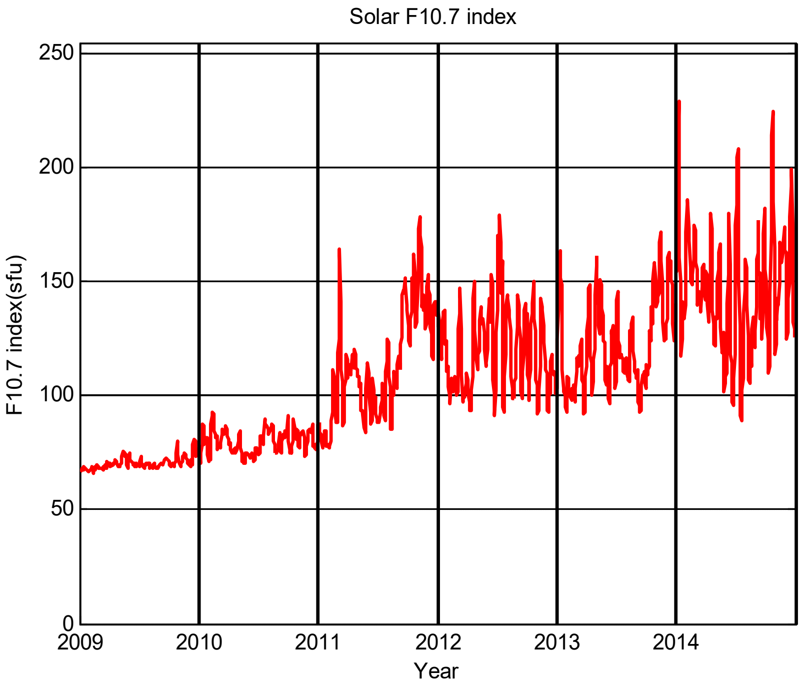
Variations of the magnetic horizontal component H and GIC during the magnetic storm on 7--10November 2004 under the transmission line Pimenta-Barreiro and at the reference station, namely, Vassouras (Trivedi et al, 2007): Brazil-low latitude..

Data and Method

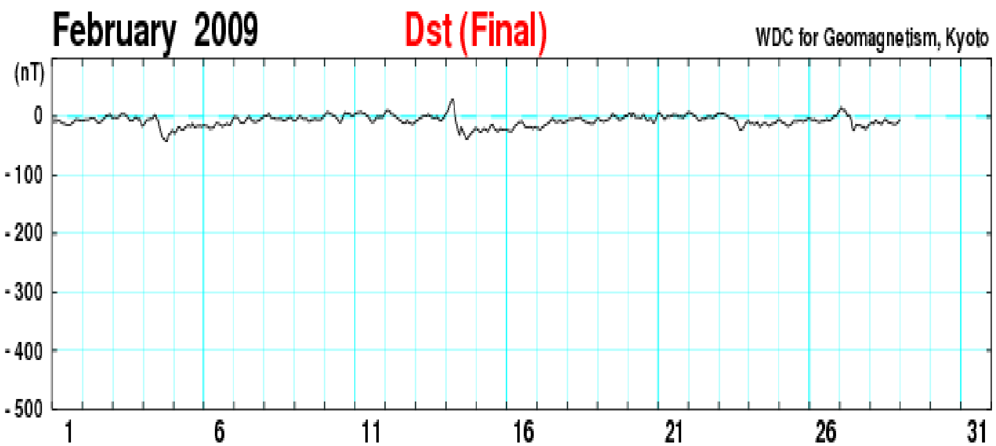


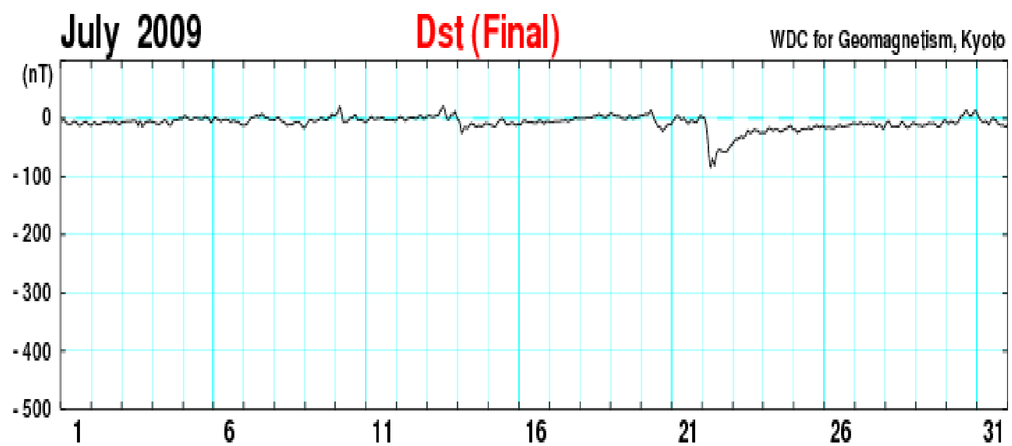
Data and method: Continuation

- Low solar activity year 2009 data
- Weak and moderate storm intensities



Data and Method: continuation





Method: Plane wave model

- **Assumptions:**

i. The Earth's resistivity structure varies only with depth.

ii. The electric field is spatially constant.

Considering a single angular frequency ω, a horizontal electric field component E_y is expressed in terms of the perpendicular horizontal magnetic field component B_x.

$$E_y = -\sqrt{\frac{\omega}{\mu_0 \sigma}}\, e^{i\frac{\pi}{4}} B_x$$

Performing an inverse Fourier transform, we obtain the time domain:

$$E(t) = -\frac{1}{\sqrt{\pi \mu_0\, \sigma}} \int_0^{\infty} \frac{g(t-u)}{\sqrt{u}}\, du = -\frac{1}{\sqrt{\pi \mu_0\, \sigma}} \int_{-\infty}^{t} \frac{g(u)}{\sqrt{(t-u)}} du$$

Method: continuation

$$g(t) = \frac{d\boldsymbol{B}(t)}{dt}$$

Summing by parts, the result is that the geo-electric field at a time $t = T_N$ is:

$$E(T_N) = \frac{2}{\sqrt{\pi\mu_0\sigma\Delta}}\left(R_{N-1} - R_N - \sqrt{M}b_{N-M}\right)$$

where Δ is the sampling interval, M is the number of previous time steps taken into account, N is the sampling number and

$$R_N = \sum_{n=N-M+1}^{N} b_n \sqrt{N-n+1} \quad ;$$

$$b_n = B_n - B_{n-1}$$

and B_n is the geomagnetic component at time t_n

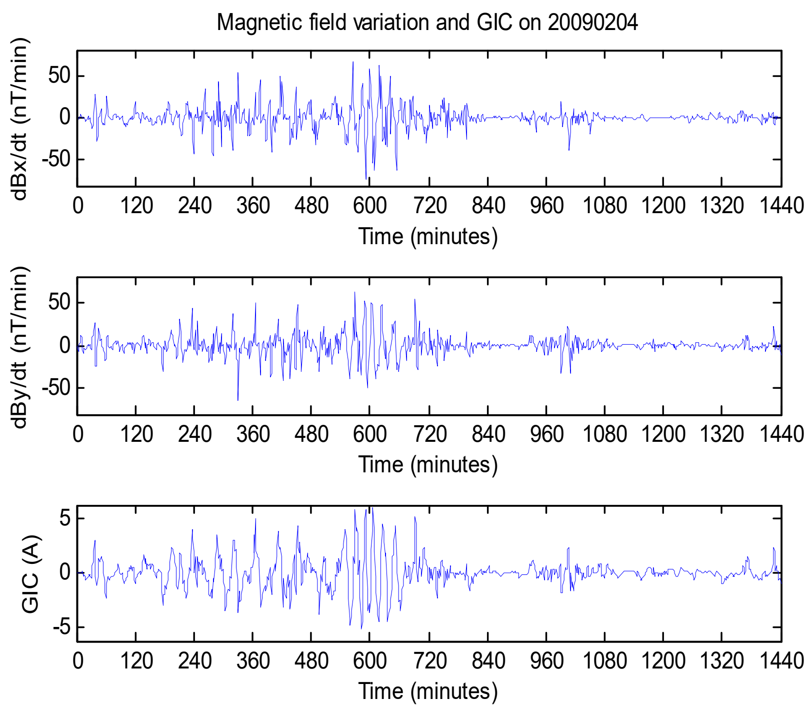
Method: Continuation

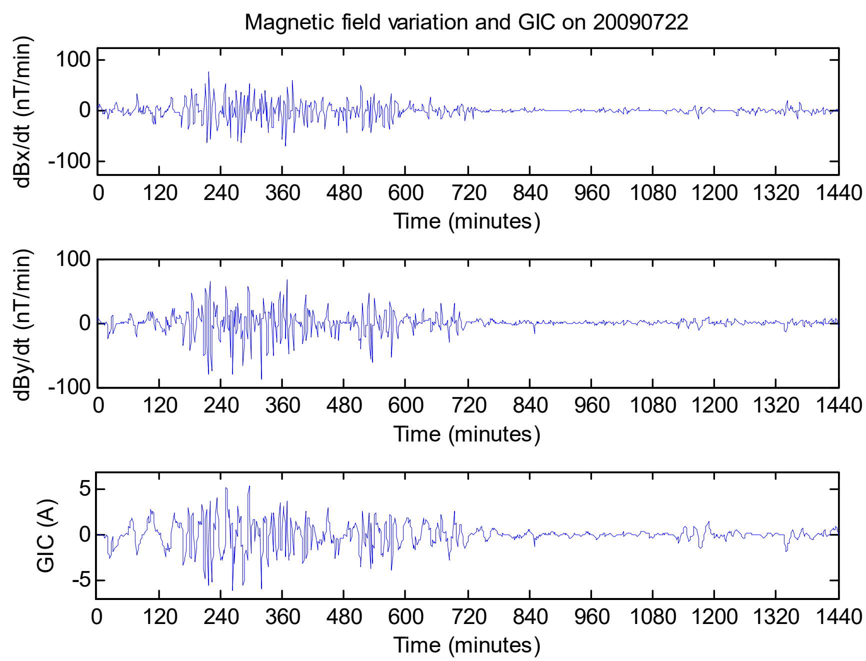
- Assuming that the electric field is spatially constant over the region (induced by a plane wave and in a region of constant ground conductivity), then the GIC can be calculated from:

$$GIC\ (t) = aE_x(t) + bE_y(t)$$

where a is the network constant for the Northward surface potential and b is the network constant for the Eastward surface potential.

Preliminary results and discussion





Preliminary results and discussion: Continuation

Date of event	$\max\left\|\frac{dB}{dt}\right\|$(nT/min)	max $\|GIC\|$(A)	Event on grid	Description
20090204	73.5054	6.1508	20090206	Blown out Jumper at Kileleshwa and Cianda
20090722	87.7287	6.2327	20090726	Burnt transformer link s/s at Hurlingam

$\max\left|\frac{dB}{dt}\right| > 30\,\frac{nT}{min}$;$max|GIC| > 5\ A$ can pose a risk to power transformers driving them into saturation.

Conclusions and future work

- Computed GIC values reaching a magnitude of about 6.2 A have been inferred to have flowed through the Nairobi, Kenya electric power grid during the two geomagnetic storms. Higher values of GIC are expected during more intense geomagnetic storms.

- For each geomagnetic storm, there is a corresponding power system event within the same week in Nairobi, Kenya.

- If funding is available, GIC monitors will be purchased and used to validate the computed results in the future.

Acknowledgment

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- ***Thank you all for your attention***