Geomagnetically Induced Currents (GIC) in Power Networks as a Source of Electromagnetic Sounding Data

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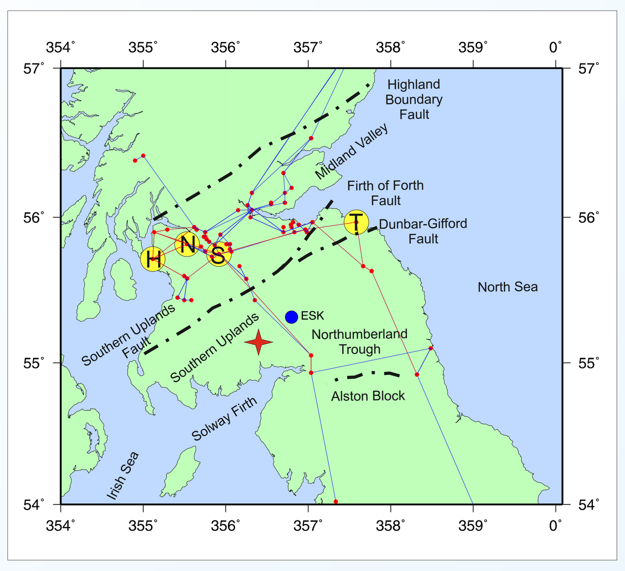
Geomagnetically Induced Currents (GIC), which can flow in technological systems such as power transmission grids, are a consequence of the geoelectric field induced at the surface of the Earth during geomagnetic storms. Since 1999 the British Geological Survey have, in conjunction with Scottish Power Plc, been monitoring GIC at four sites in the Scottish Power high-voltage transmission network. The main purpose of the monitoring project is to try to understand the risk posed to the power network by GIC. However, this poster investigates the feasibility of using GIC data in order to investigate long-period induction in the central Scotland and northern England region. We have already investigated the joint spectral characteristics of the GIC and geomagnetic observatory data from Eskdalemuir in the Scottish Borders, and GIC have been shown to be coherent with magnetic field variations in a period range which extends from 10-2,000 s. In addition, we found that the phase response of a frequency dependent bi-variate transfer function model of the physical link between magnetic field variations and GIC may be interpreted in a similar manner to Magnetotelluric impedance phases. However, the quality and long period resolution are limited by the available data which is mostly collected in 12-24 hour segments. Therefore, the possibility of extending the period range, and optimising the quality of the data, by collecting and analysing longer segments of data, is investigated.

Background



The Scottish Power (SP) high-voltage electricity transmission network is situated in the Northern England and Southern Scotland region, and encompasses the geological terranes of the Midland Valley and Southern Uplands; see Figure 1. We consider GIC data from Strathaven (STHA; marked S in Figure 1) and magnetic data from Eskdalemuir (ESK) geomagnetic observatory.

STHA is a particularly interesting site because the main connections are approximately parallel and perpendicular to the strike of the Southern Uplands (SU) and Midland Valley (MV) terrane boundaries. GIC are measured in the neutral 'earth' connection of the power transformer; see Figure 2.

Figure 1 (above): *A sketch of the SP 275 (blue) and 400 (red) kV network. Red circles denote the location of power transformers. Scottish Power Plc monitor GIC at four points (yellow circles) in the grid: Hunterston (H), Neilston (N), Strathaven (S) and Torness (T). The red star shows the location of a Magnetotelluric site in Tauber's 2003 survey [1].*

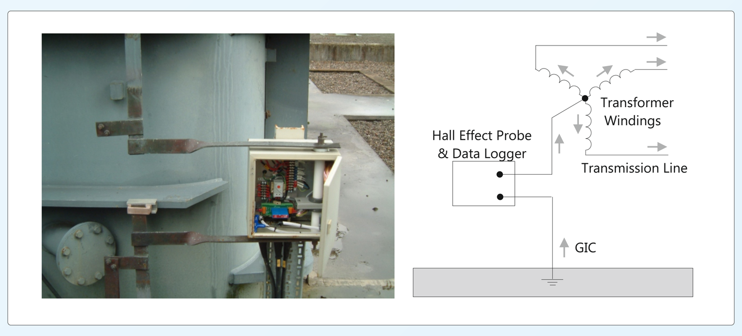
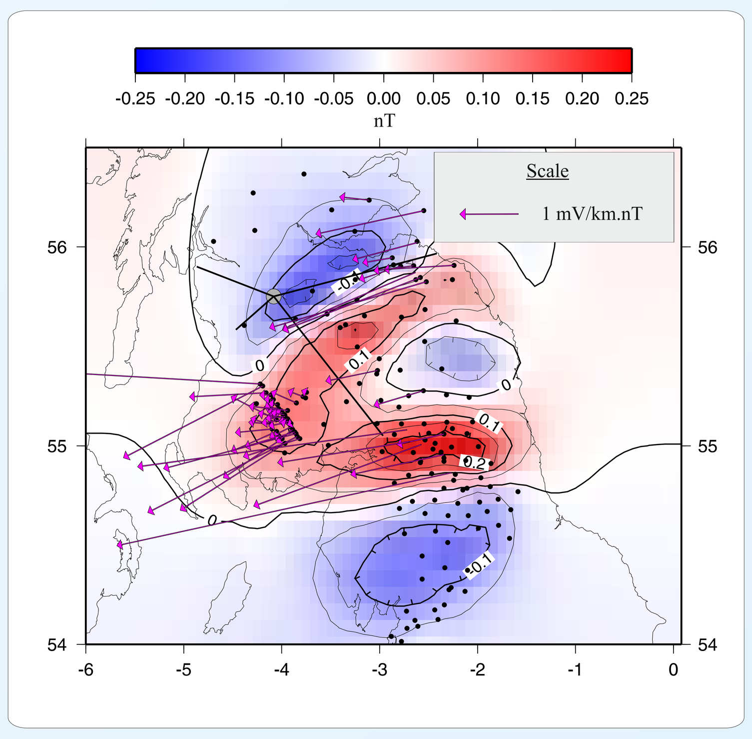


Figure 2 (above): *A picture and sketch of the GIC monitor at Strathaven.*



Two major mid-crustal conductivity anomalies are present in the region [e.g. 1] These can be seen using a hypothetical event map [e.g. 2] of the real part of the anomalous geomagnetic induction and telluric vectors [3]; see Figure 3. The SU anomaly strikes NE-SW; the Northumberland Trough (NT) anomaly E-W.

Figure 3: *A hypothetical event map showing contours of the real part of the anomalous geomagnetic induction and telluric vectors calculated from Geomagnetic Deep Sounding (GDS) and Magnetotelluric (MT) data at a period of 750s. The MT tensors were first 'corrected' for the effects of galvanic distortion using tensor decomposition [4] before calculating the telluric vectors. Zones of comparatively high conductivity are implied by the red-shading. The main 400 kV connections to STHA are shown as thin black lines.*

The magnetic data consist of high-quality 1 Hz samples of the geomagnetic field at Eskdalemuir (ESK). The GIC data are sampled at 10 Hz. To enable comparison with the magnetic data we resample the 10 Hz GIC data to 1 Hz by computing one-second means centred on each second. The STHA data were collected in May 2005 and consist of 31 days of complete data.

We wish to :

- establish if the magnetic and GIC data are correlated at long periods;
- assess the joint amplitude and phase characteristics of the magnetic and GIC data.

Data Analysis - Wavelet Coherence

The correlation between hourly means of the ESK and GIC data was investigated using the wavelet coherence [5] .

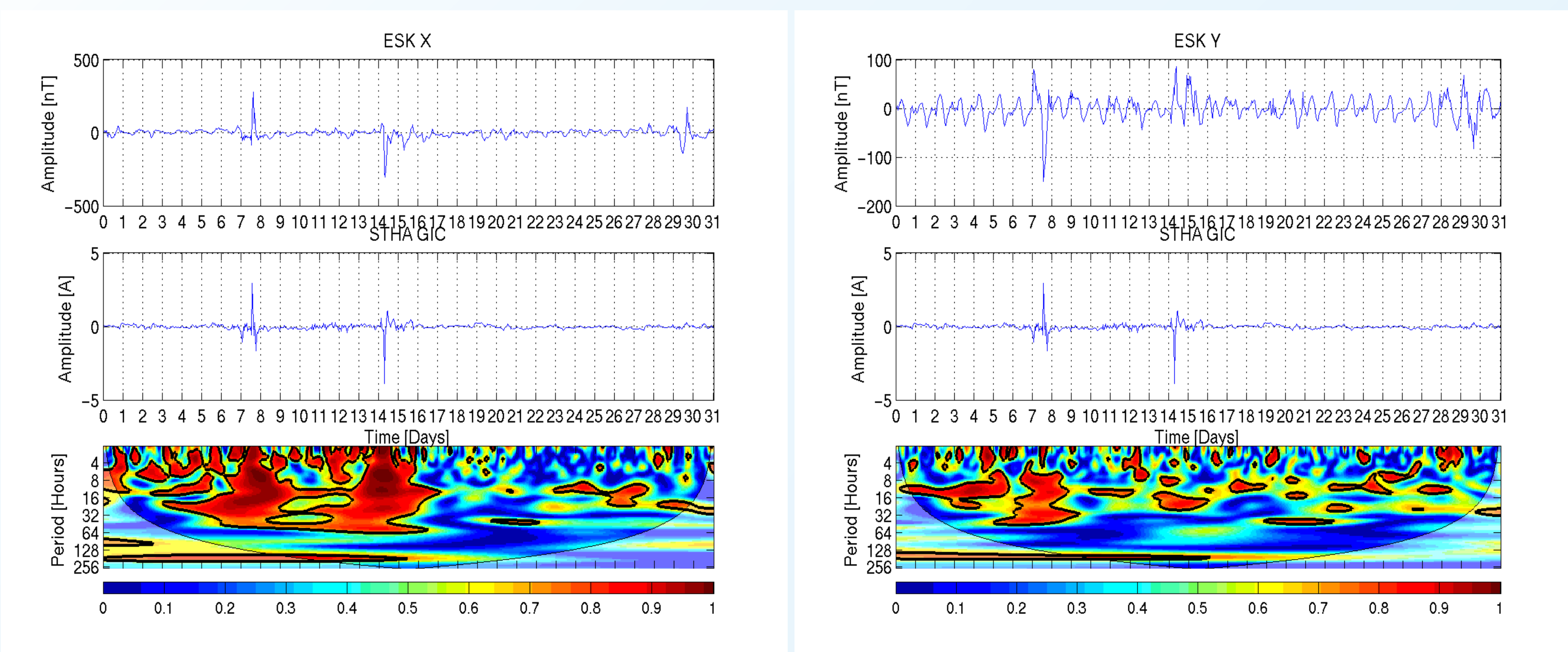


Figure 4 (above): *The coherence (bottom panel) of the ESK X (left; top panel), ESK Y (right; top panel), the geographic north and east components respectively, and STHA GIC (middle panel). The complex Morlet wavelet was used. The statistical significance of the coherence is tested using Monte-Carlo methods assuming a red-noise process; the first order auto-regressive co-efficients were determined from each of the time-series. The thick black contour denotes the 5% significance level against red-noise; the dimmed plot area is contaminated by edge effects. Time is days from 1 May 2005.*

We find that the correlation between STHA GIC and the geomagnetic field components at periods greater than 1 hour is both time and period dependant.

Two geomagnetic storms occurred on the 8th and 15th of May 2005. The coherence is maximum during geomagnetic activity. However, a coherent long-period signal can still be detected during geomagnetically quiet periods.

The most persistent zones of coherence over the whole time frame occurs at a period of about 12 hours.

Response Function Estimates

To study the joint amplitude and phase characteristics of the magnetic and GIC data we assume a linear relationship between the horizontal components of geomagnetic induction (*Bx,By; geographic north and east respectively)* and the measured GIC, viz.

$$GIC(f) = Tx(f)Bx(f) + Ty(f)By(f) + n(f)$$

where $Tx(f)$ and $Ty(f)$ are the transfer functions, f is the frequency and $n(f)$ is the noise [e.g. 6]. A robust statistical method was employed to calculate the transfer functions [7]. Visual inspection of the complete time-series revealed few gross outliers. Therefore, all of the available one-second GIC and magnetic data were used.

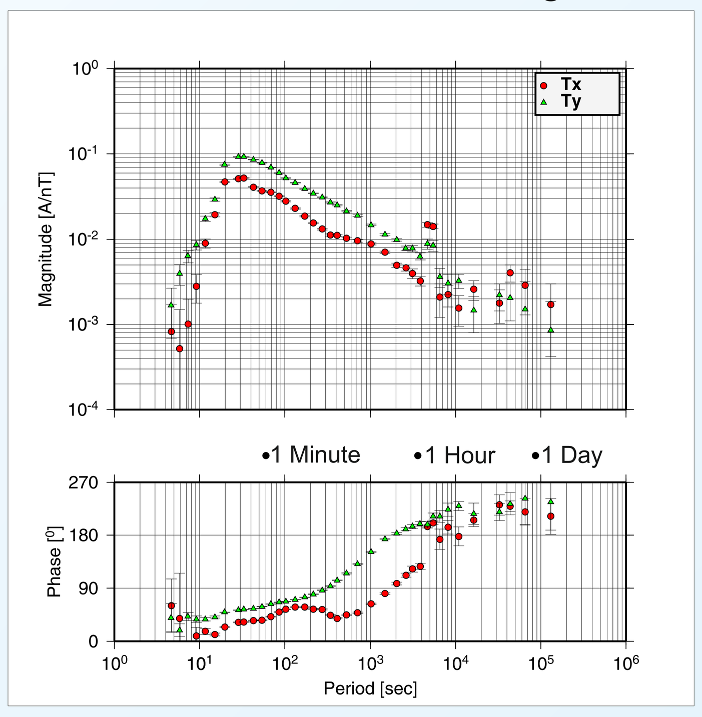


Figure 5: *The computed STHA transfer function magnitude [A/nT] and phase [degrees] response. The equivalent period of one-minute, one-hour and one-day is shown between the amplitude and phase plots. Estimates are frequency band-averages which are arranged to be approximately evenly spaced in log10(period).*

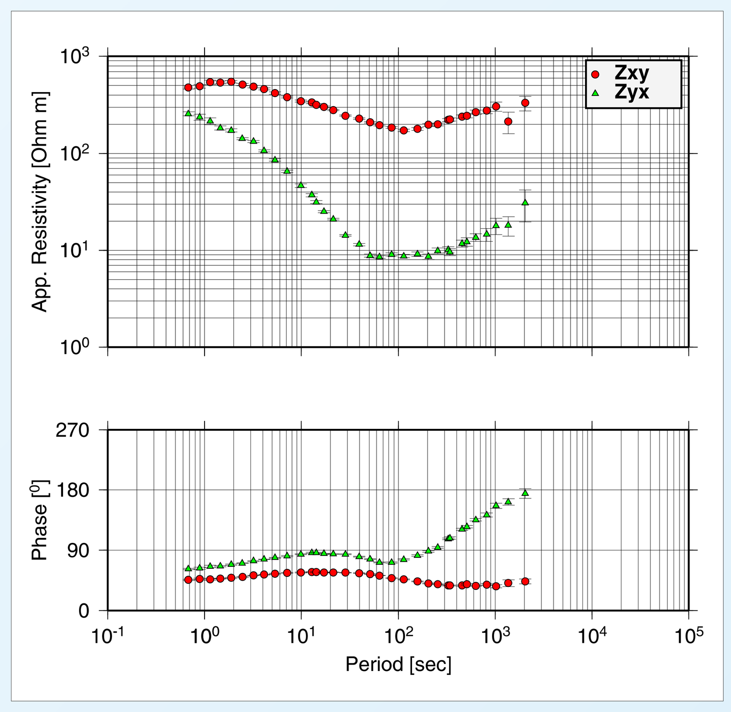


Figure 6: *MT response (geographic co-ords.) representative of sites at the southern end of the main survey of [1]. The site is situated near the 'knee' join of the SU and NT anomalies; sites in this location all display out of quadrant phases (> 90 degrees) at long periods. Most sites in the profile display the phase enhancement (> 45 degrees) in the 10-100 s period range.*

It is commonly assumed that GIC flow in power networks in an Ohmic manner [8]. This implies that the GIC transfer function phase should contain information about the Magnetotelluric impedance phase. Qualitatively, there is some agreement between the GIC *Tx* and *Ty* phases (Figure [5]) and the *Zyx* MT phase (Figure [6]). Both display a phase enhancement (phase > 45 Degrees) in the 10-100 s period range which is consistent with a mid-crustal conductor. In addition, the phase rolls smoothly out of quadrant at periods greater than 100 s.

Conclusions and Future Work

Conclusions

We found significant long-period coherence between the ESK magnetic data and STHA GIC.

The STHA GIC transfer function phase compares reasonably with the MT impedance phase from a typical MT site close to the southern end of one of the main STHA power lines.

Future Work

The initial analysis is encouraging and we intend to initiate longer term collection of GIC data from all four monitoring sites in the power network.

It is probable that the transfer functions change as the power network evolves therefore we intend to investigate how stable the estimates are in time.

We will investigate if network and geo-electric field models may be used to convert the GIC response to a network MT response [e.g. 9 & 10] .

Acknowledgements:

ScottishPower

References:
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