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Long Period Magnetotellurics (MT) using Geomagnetically Induced Currents in the Scottish Power Network

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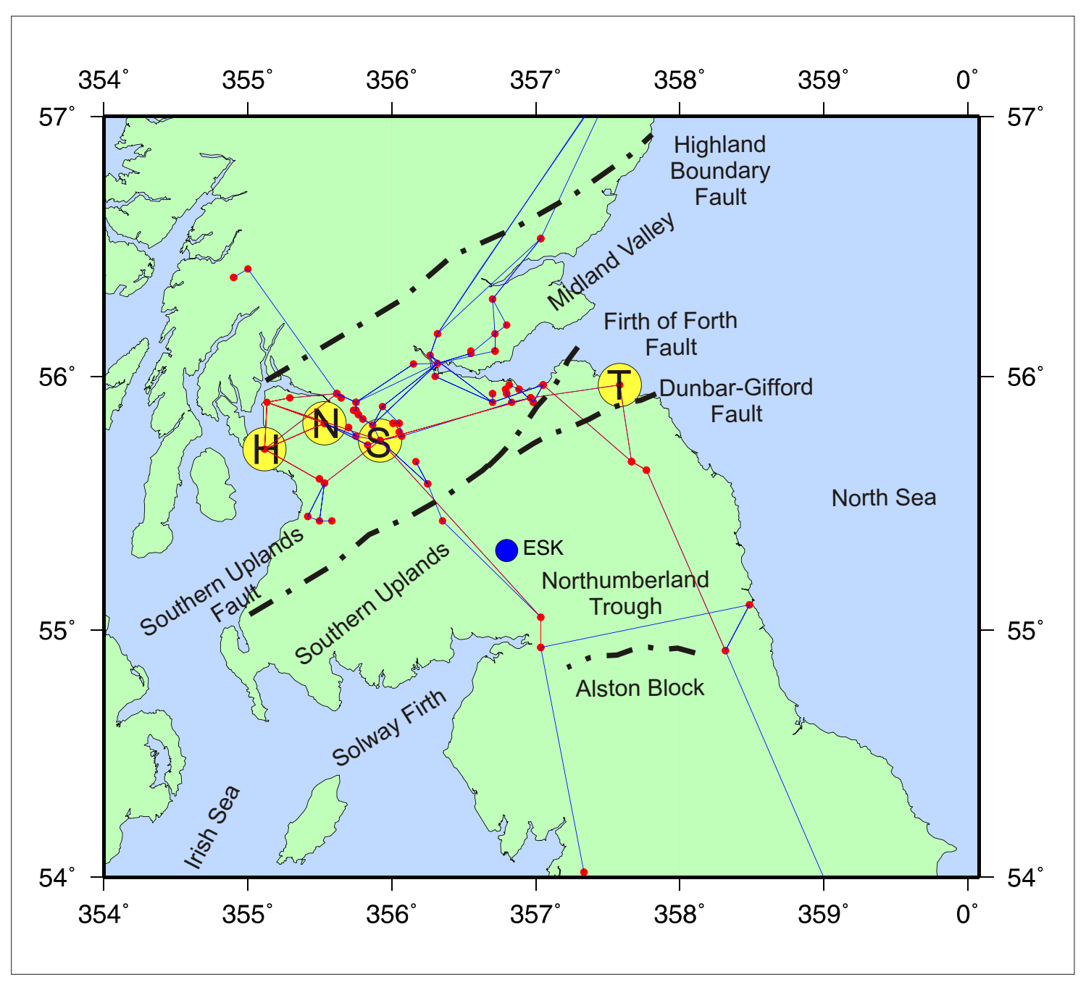
Abstract: Geomagnetically Induced Currents (GIC), which flow in technological systems such as power transmission grids, are a consequence of the geoelectric field induced at the surface of the Earth during geomagnetic storms. We use an electrical model of the power network, measured GIC data and geomagnetic data from Eskdalemuir observatory to estimate the MT parameters apparent resistivity and phase. The long period MT responses are generally smooth and stable over a period range which extends from about 200-40 000s. We invert the apparent resistivity and phase for a smooth 1D resistivity model using an Occam algorithm.

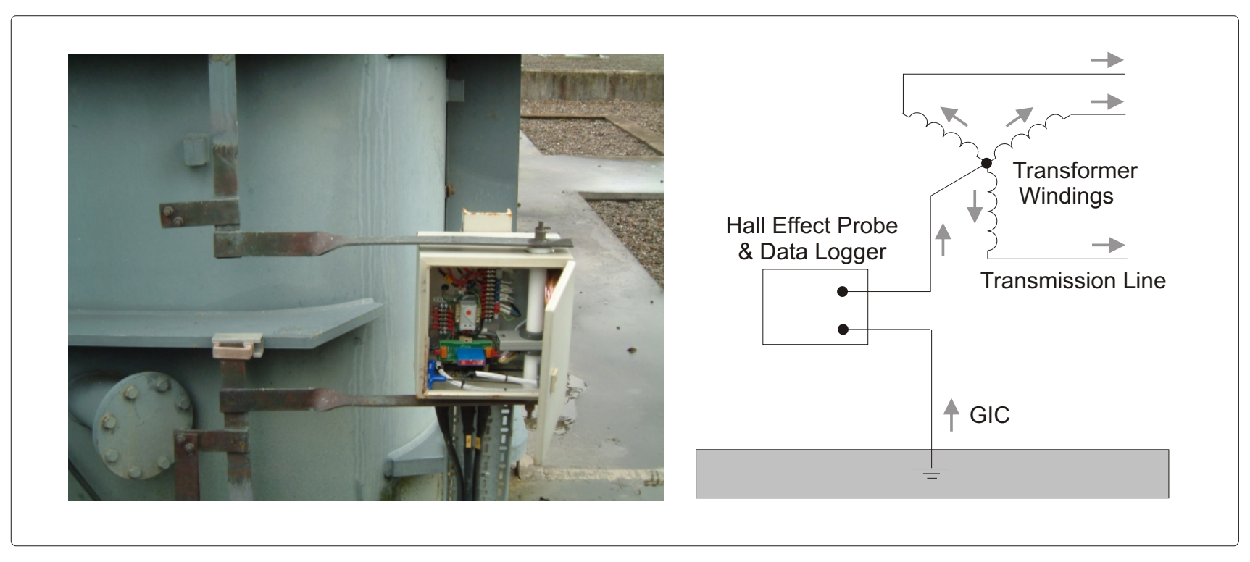
1. Background

We show that power network GIC, and magnetic observatory data, can be used to estimate the Magnetotelluric apparent resistivity and phase. Previous studies are limited and considered mainly pipeline GIC (see Pulkkinen *et al.* 2007).



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 left. We use GIC data from Strathaven (STHA; marked S in Figure) and magnetic data from Eskdalemuir (ESK) geomagnetic observatory collected during May 2005.

GIC are measured in the neutral 'earth' connection of the power transformer using a Hall-effect probe; see Figure right.



2. Data Analysis

Pulkkinen *et al.* 2007 showed that, assuming a 1D resistivity structure, the MT impedance (*Z*) can be determined from measured GIC in pipelines e.g. in the frequency domain

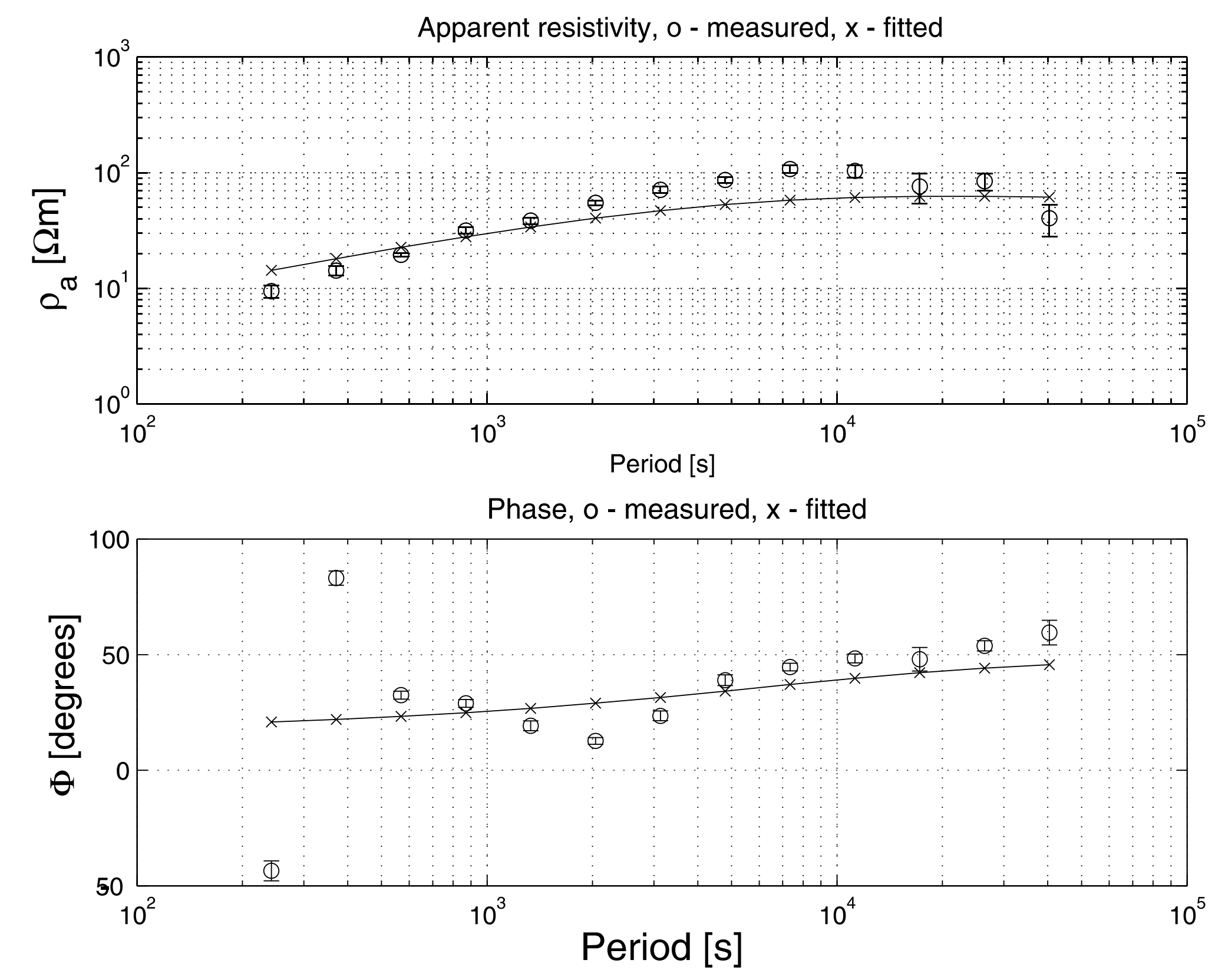
$$Z=\mu_0 GIC[1/(aB_y - bB_x)]$$

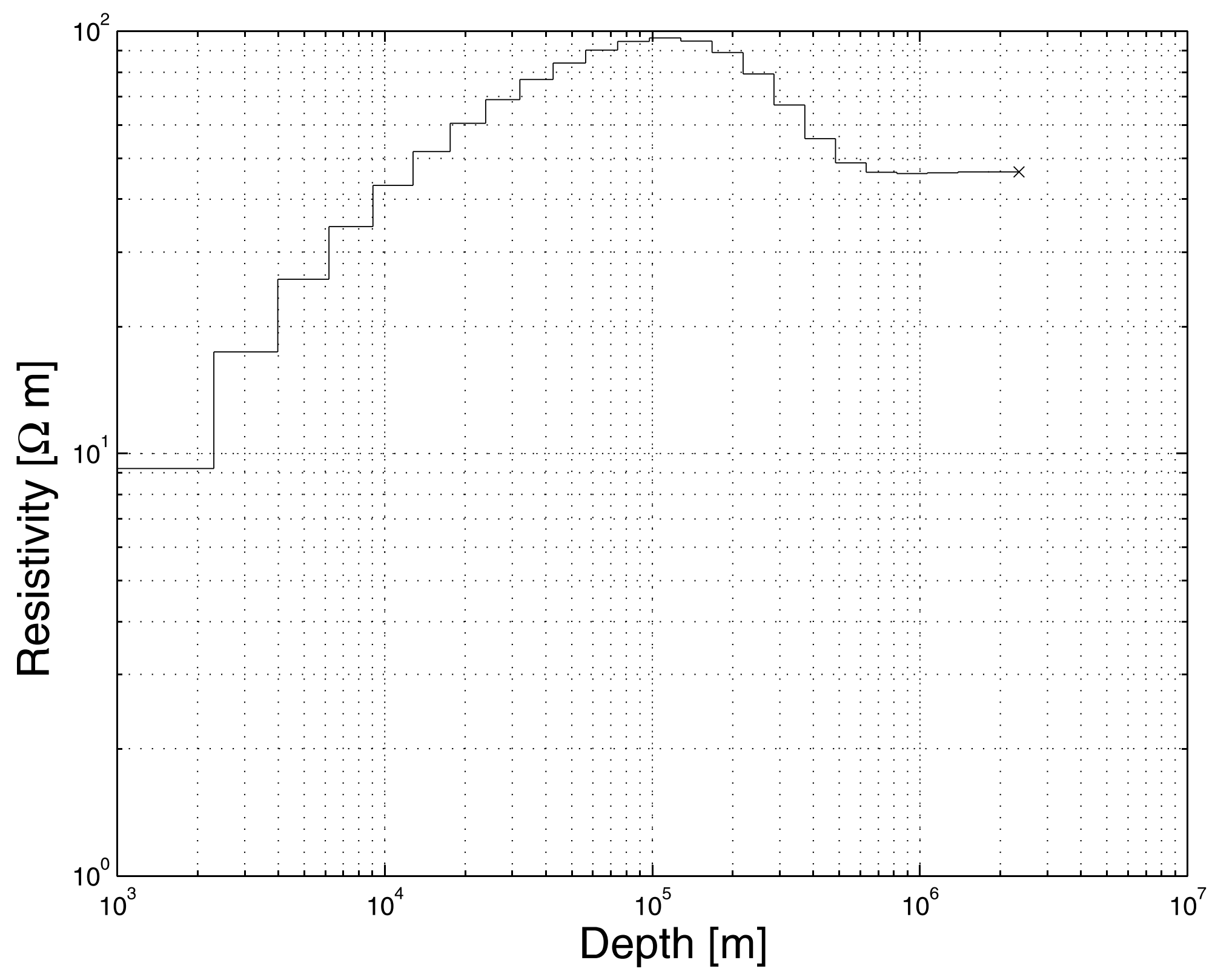
where *a* and *b* are site-dependent system parameters which depend on the electrical characteristics and network topology of the system under investigation, *Bx* and *By* are the horizontal magnetic field components and μ_0 is the permeability of free-space.

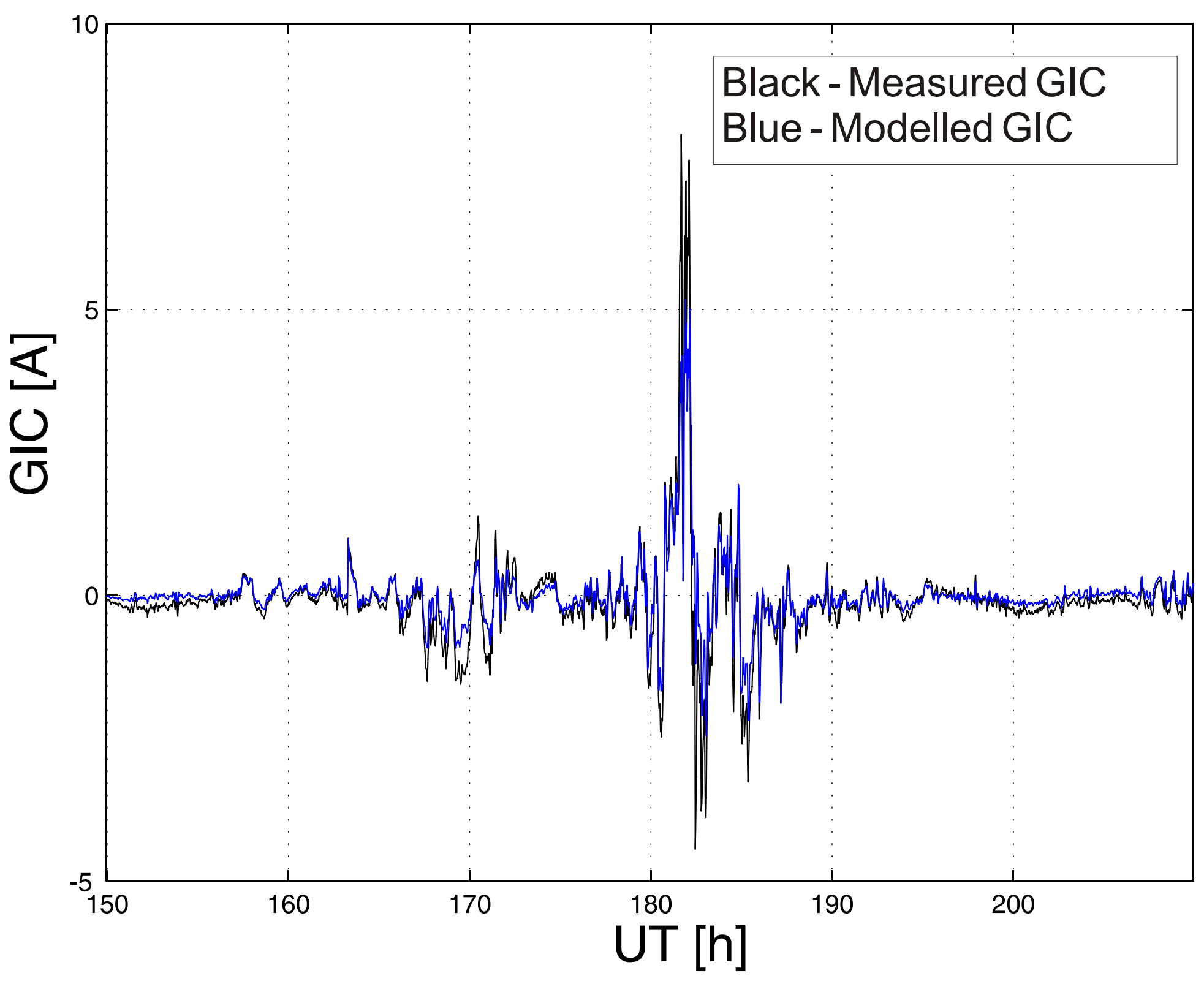
From magnetic and GIC data alone we can determine only the ratio *c* = *b*/*a* via auto and cross correlation (or equivalently spectral) analysis of the magnetic and GIC data (see Pulkkinen *et al.* 2007 for details). On the basis of network analysis of the Scottish Power grid (e.g. Lehtinen and Pirjola, 1985) we fixed *a* to -23 Akm/V and determined the ratio *c*; this gave *b* = -59 Akm/V. Using the a and b determined from network analysis alone gave much poorer results.

We determined the MT impedance using a Robust M-estimation scheme (e.g. Egbert and Booker 1986; Eisel and Egbert 2001). Confidence limits were determined by a boot-strapping procedure of repeating the analysis 30 times with different randomly selected (with replacement) subsets of the data. To determine stable long-period MT parameters we found it necessary to shift the GIC time-series by 147s to align it with the magnetic reference time-series, and average the 1s samples to 100s means. We inverted the apparent resistivity and phase data for resistivity using a 1D Occam Inversion (e.g. Constable *et al.* 1987).

3. Results







The apparent resistivity (left panel) is stable across the whole long-period range; the first two phase data are not self-consistent but are thereafter smooth and stable.

The apparent resistivity curve is generally suggestive of increasing resistivity with depth although it does level off (or even decrease) at the longest periods. Phase values are typically less than 45 degrees, with a minimum at about 2000 s, again indicative of a general increase of resistivity with depth or a layer of higher resistivity. Indeed, the results of the inversion (middle panel) show resistivity increasing until about 10 km depth, and thereafter decreasing. These results are consistent with conventional MT studies in the region (e.g. Banks *et al.*, 1996) which reveal a gross structure of the Midland Valley terrane that consists of a surface conductor and resistive upper crust (to a depth of about 10km) overlying a mid crustal conductor.

We find that the system parameters and resistivity model we derived accurately reproduce the measured GIC as can be seen by comparing the modelled and measured GIC (right panel). The measured and modelled GIC exhibit a high-degree of correlation: the correlation co-efficient is 0.86.

4. Summary and Future Work

(1) We find that it is possible to derive stable MT parameters using a combination of power network GIC and magnetic observatory data;

(2) The conductivity structure determined by this study is consistent with the gross conductivity structure revealed by conventional MT studies.

We think therefore that GIC in power grids, which are often monitored for long time-periods, may provide a useful addition to field-campaign MT studies.

We do not yet understand the origin of the apparent time offset between the magnetic and GIC time-series that is visible only at long periods, and this requires further investigation as a matter of priority. In future, we will make use of GIC data from all four monitoring sites within the power network each of which should sample different conductivity structures.

References

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