**Monitoring and Analysis of Geomagnetically Induced Currents in the British Isles**

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**Previous Work**

- Monitoring Geomagnetically Induced Currents (GIC)
  - On transformers in the Scottish Power grid
  - Monitoring equipment (GIC and gas) installed at 3 sites in January 2000, now at 4 sites

- Monitoring and Predicting Geomagnetic Activity
  - Hourly geomagnetic data and daily forecast service provided by BGS
  - Used by Scottish Power in its daily operations since October 1999.

- GIC Study
  - Analysis of GIC during significant magnetic storms (2000-2002) in relation to measurements at UK and northern European geomagnetic observatories.
  - Time Domain, Frequency Domain, Linear Transfer Function Models

**Current Activities**

- Electric field modelling in the UK and continental shelf and preliminary GIC modelling in the UK power grid

**Future Developments**

- Improving services to the power industry through ESA space weather pilot project

**Previous Work: Monitoring GIC in Real Time**

Scottish Power Grid

- Hall Effect Probe
- Hydram Gas Analyser

Data are available at the grid control centre

Operator alarm set at 5 Amps

BGS supply of magnetic data is used for confirmation of current as GIC
**Previous Work: Geomagnetic Activity Monitoring**

**Hourly Standard Deviation (HSD)**

- Gives an indication of the total magnetic spectral power during the hour
  - related to the surface electric field through the magnetotelluric relation, $E(w) = Z(w) H(w)$
- Simple index to compute
  - real-time on-line provision made possible
- Magnetic substorms typically last 10 minutes to a few hours
- Single data spikes unlikely to have an effect
  - important when operating automatically in real time.

**UK magnetic observatories**

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**Previous Work: Geomagnetic Forecasts**

**Geomagnetic Activity Forecasts**

- gives broad view of likely activity for non-specialist
- attempts to relate to conditions observed in UK

**UK magnetic observatories**

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**Current Activities: Conductivity and Electric Field Models of UK Continental Shelf**

**Thin Sheet Model**

- appropriate to 'low frequency' GIC range of 100-1000s
- Horizontal field only required
- Non-uniform source fields can be used
- Includes shelf seas and bathymetry

**UK magnetic observatories**

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Current Activities: Electric Field

Example North - South plane wave magnetic variation (East – West ionospheric electrojet) at 750s period

Regional East-West E-field from thin sheet model

Anomalous North-South E-field resulting from lateral changes in conductivity – significantly more complicated in central Scotland

E-field magnitude and direction (mV/km.nT)

Current Activities: Comparison with Data

Under assumption of induction in the Earth via quasi-uniform sources, a vertical field indicates presence of lateral changes in conductivity.

Induction arrows (right) are determined from the transfer functions that relate the vertical field to horizontal driving fields. They point to concentrations of electrical current (e.g. conductivity contrasts).

Model (scale = 0.5 per nT; period = 750s)

Conductance map compatible with measured induction arrows

Measured Data (20 years of field campaigns by Univ. Edinburgh)

Future Opportunities: Grid Operator Issues

Key Issues for Improved Service to Industry – based on discussions with Scottish Power

Increased warning time of CME arrival, based on L1 monitor – automated shock monitoring

Estimates of peak GIC magnitude in the grid – where are the biggest currents flowing in response to geomagnetic drivers?

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Current Activities: GIC Modelling in Association with FMI

Below: Dependence of GIC on source field polarisation.

Right: Simple model of constant E-field.

Right: E-field with lateral variations in conductivity, and sea water.

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Future Opportunities: ESA Pilot Project (1)

The Partnership.
BGS as service developer and Scottish Power as the service user.
Aiming for simple, yet reliable system within financial constraints set by pilot project.

The Proposed Solution.
(1) Interplanetary shock detection: pattern recognition and event detection techniques, e.g. neural networks, wavelet and spectral analysis. More than one algorithm for robustness.
(2) Grid GIC model: merging a model to compute the flow of GIC in the Scottish power network with a model that computes the induced surface electric field which drives the GIC. The induction model will take as input the magnetic variations recorded at the UK observatories operated by BGS, or simplified electrojet structures.

The current reliable BGS-SP communication system will be augmented to transmit relevant warnings and data to the Scottish Power grid control room.

Future Opportunities: ESA Pilot Project (2)

Benefits.
(1) Economic benefit to user – addresses user’s concerns
(2) Potential application beyond UK grid – dependent on scale size of variations
(3) Public awareness – adding to real time monitoring on BGS web pages

Prior Experience.
(1) Progressive development of GIC expertise and in service provision
(2) Near real time data acquisition, processing and delivery, e.g. magnetograms for geophysical exploration

Data Requirements.
UK geomagnetic data and public domain L1 data

Development Risks.
(1) Spiky/noisy/missing data – real time data management issues
(2) Variability of ionospheric driving currents – ‘blue sky research’
(3) Accuracy of shock monitor & GIC estimates – ‘fit for user purpose’

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Reviewed Previous Activities on GIC
– in association with Scottish Power plc, FMI

Summarised Current Activities
– electric field modelling in the UK and nearby continental shelf

Identified Opportunities for Future Developments
– improving service to industry through space weather pilot project

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