Differential Magnetometer Measurements in the UK High-Voltage Power Grid

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NAM2019 SWIGS SPACE WEATHER IMPACT ON GROUND-BASED SYSTEMS

Overview

Extreme space weather events can pose risks to ground-based infrastructure like high voltage (HV) transformers, railways and gas pipelines through the induction of geomagnetically induced currents (GICs). Modelling GICs requires knowledge about the source magnetic field and the electrical conductivity structure of the Earth to calculate the electric fields generated during enhanced geomagnetic activity. Ideally we would validate the modelled GIC at high voltage transformer grounding points. However, this is not economically feasible as power companies cannot instrument all transformers.

We use the **Differential Magnetometer Method (DMM)** to indirectly measure GIC in HV lines rather than GIC through ground points.

1. DMM Hardware and Method

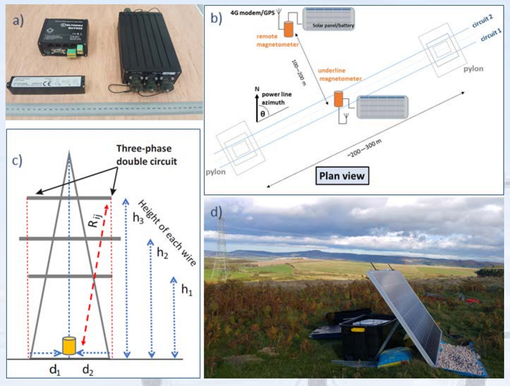

Figure 1: Hardware and setup of a DMM station. a) 4G network modem, EarthData digitiser, fluxgate magnetometer (clockwise from top left). b) Schematic plan view of underline and remote systems at DMM site. c) Geometry for sensor location and the wires in the A-frame pylon model. d) Complete setup at station Ilderton, Northumberland (ILD) with buried sensor, solar panel and mobile aerials.

2. DMM Sites

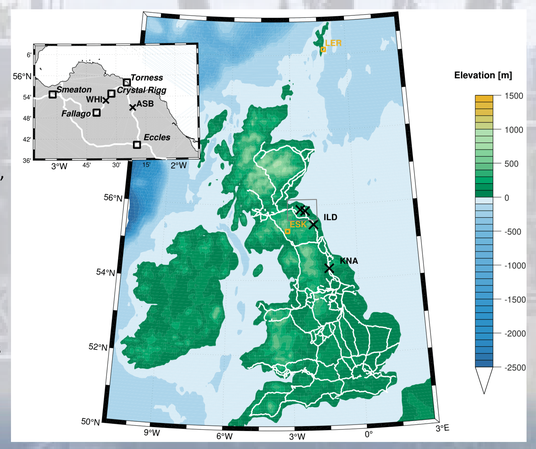

Figure 2: UK High Voltage transmission network (white lines) and location of SWIGS magnetometers in 2018 (black crosses, WHI- Whiteadder, ASB Abbey St. Bathans, ILD Ilderton, KNA - Knayton). Geomagnetic observatories (orange squares, LER- Lerwick, ESK - Eskdalemuir). **Inset:** the location of substations (black squares) and DMM sites near Torness power station (in eastern Scotland, see Fig 5).

3. GIC measurements with DMM

Date	Storm	Detail	SWIGS magnetometers
24-26 August 2018	**G3** **Kp 7+**	Largest geomagnetic storm of 2018 (G3), Kp max was 7+, Ap 67, solar wind peaked at 553 km/s, |IMF| reached 21 nT, prolonged southward Bz (min -17nT). Coronal mass ejection from Aug 21-22 2018, no classic shock impact so slightly surprised forecasters.	Whiteadder (WHI)
4-6 November 2018	**G2** **Kp 6-**	No. 4 in the top list of geomagnetic storms for 2018 (G2). Kp max was 6-, Ap 32, solar wind peaked at 631km/s, |IMF| reached 16nT, max southwards Bz -11nT. Due to enhanced solar wind from trans-equatorial coronal hole.	Whiteadder (WHI) Abbey St. Bathans (ASB) Ilderton (ILD) Knayton (KNA)

August 2018

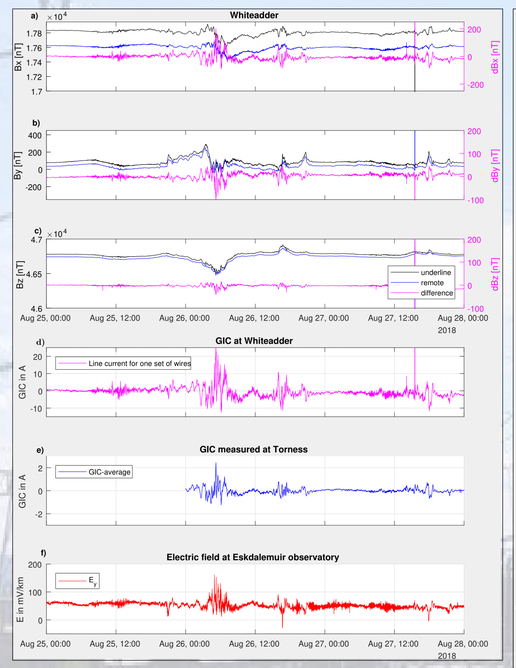

Figure 3: Recorded times series during the G3 geomagnetic storm on 25-27 August 2018.
(panels a-c) Magnetic field components at DMM site Whiteadder, East Lothian (WHI), (panel d) estimated line GIC at WHI; (panel e) GIC data from a transformer Hall probe at Torness substation; (panel f) East-West component of the electric field measured at the observatory in Eskdalemuir, Scottish Borders.

The magnetic signal associated with the line current is most dominant in the horizontal components and can be maximised into one component by rotation into a power line-parallel coordinate system (see yellow box, right).

November2018

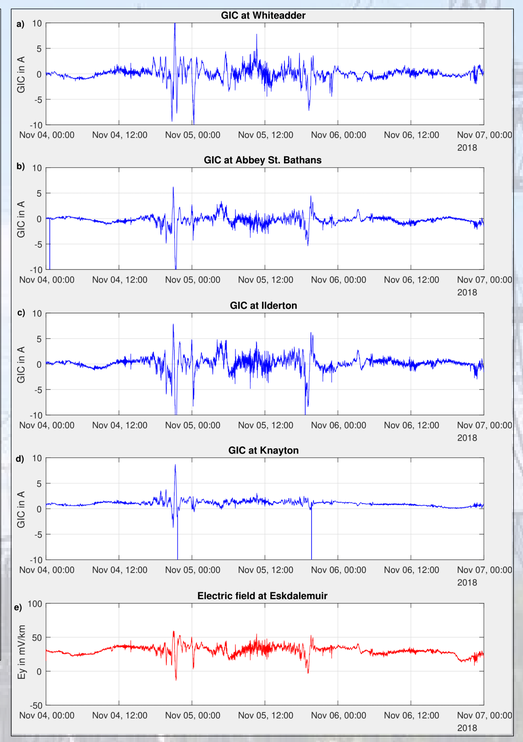

Figure 4 (right) (panels a-d): Estimated line GIC measured with DMM at four SWIGS sites during the 5 November 2018 storm and (panel e) the East-West component of the electric field measured at the observatory in Eskdalemuir.

GIC is generally smaller further south, except at Ilderton, probably because it is a long north-south orientated line with lower resistance transformers at either end.

4. Validation of HV network model

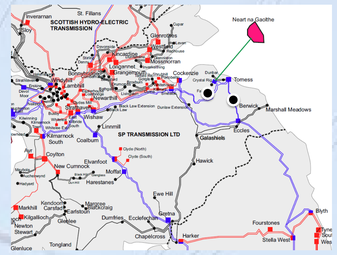

Figure 5: Layout of the high voltage electrical network in southern Scotland:
Blue: 400 kV
Red: 275 kV
Black: 132 kV

Black dots are:
WHI (Torness to Smeaton) and ASB (Torness to Eccles)

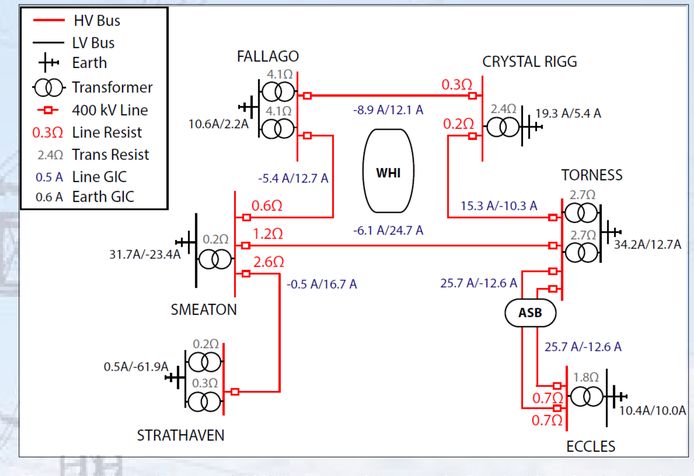

Figure 6: Circuit diagram of 400kV power grid system in East Lothian, Scotland, with location of DMM stations WHI and ASB. Line currents (per phase) in the transmission lines and total Earth GIC in the transformers for North-South and East-West oriented electric fields of 1 V/km were calculated using the GB network model and thin-sheet conductivity distribution described in Beggan et al. (2015) and Kelly et al. (2017). WHI – DMM site at Whiteadder, East Lothian; ASB – DMM site at Abbey St. Bathans.

Analysis of measured vs modelled on 26th Aug 2018

Measured
At ESK; geoelectric field (E-W) peak: ~140 mV/km
At WHI DMM; peak B field: ~225 nT
At TORNESS Hall probe; 2 A

Modelled (from Fig 6):
At TORNESS: 12.7 A * 0.140 = ~2 A ✓
Along WHI Line: (24.7 * 3 + 12.1 * 3) A * 0.140 * distance to wires ~ 225 nT ✓

Acknowledgments

SWIGS is a UK Natural Environment Research Council funded study into 'Space Weather Impacts on Ground-based Systems' (grant no. NE/P017231/1). The authors would like to thank the BGS Geomagnetism engineering team Tim Taylor, Tony Swan and Chris Turbitt for the design and building of the instruments and the landowners for access permissions during field work.

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