APRIL 2000 STORM: IONOSPHERIC DRIVERS OF LARGE GIC

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ABSTRACT

Geomagnetically induced currents (GIC) flowing in technological systems on the ground are a direct manifestation of space weather. Due to the proximity of very dynamic ionospheric current systems, GIC are of special interest at high latitudes where they have been known to cause problems, for example for normal operation of power transmission systems and buried pipelines. In this study, the geomagnetic storm of April 6-7, 2000 is investigated. During this event, GIC were measured in technological systems both in Finland and in Great Britain. This therefore provides a basis for a detailed GIC study over a relatively large regional scale.

INTRODUCTION

Rapid geomagnetic variations were first connected with induction phenomena and electric currents flowing in technological systems on the ground in the mid 1800s. In particular, geomagnetically induced currents (GIC) were found to cause disturbances in the operation of telegraph equipment [3]. Since then the number of technological systems having long conductors has rapidly increased, and various networks, such as power transmission systems, buried pipelines, telecommunication cables and railway signalling systems have been found to be affected by GIC to varying degrees [10; 7].

Despite numerous studies of GIC, there still exists no well-established picture of the detailed structure of the ionospheric currents driving the largest GIC. Some rough estimates of electrojet intensity and morphology during GIC events have been carried out [11; 4; 5; 6; 13], but no rigorous study of realistic ionospheric source currents is available.

In this study we investigate a single intense geomagnetic storm: the event of April 6-7, 2000. The main aim is to look at the dynamics of the ionospheric currents during large GIC to better understand the charateristics of the ionosphere-magnetosphere system underlying GIC.

DATA SOURCE AND ANALYSIS METHODS

The geomagnetic data used in the study were obtained from the IMAGE and SAMNET magnetometer networks operating in the northern part of the Europe (see Fig. 3). GIC measurements were obtained from the Scottish and Finnish high-voltage power transmission grids and from the Finnish natural gas pipeline network (see Fig. 3). Ten-second data for both magnetic and GIC data are used.

The geomagnetic data were investigated by the spherical elementary current system (SECS) method [1]. In this approach, the ground magnetic data are converted to ionospheric equivalent current density patterns. Here equivalent currents were used to identify the ionospheric drivers of large GIC.

To examine the characteristics of the induced electromagnetic field at the surface of the Earth, we compute the time derivative of the ground horizontal magnetic field ($d\mathbf{H}/dt$), to give a reasonable measure of the induction or GIC activity [14]. We then rotate the computed $d\mathbf{H}/dt$ vectors 90 degrees anticlockwise, to be roughly parallel to the electric field, $\mathbf{E}_{sur}$, at the surface of the Earth. Because only the basic structure of the induced field is of our interest here, $d\mathbf{H}/dt$ is identified with $\mathbf{E}_{sur}$ below.

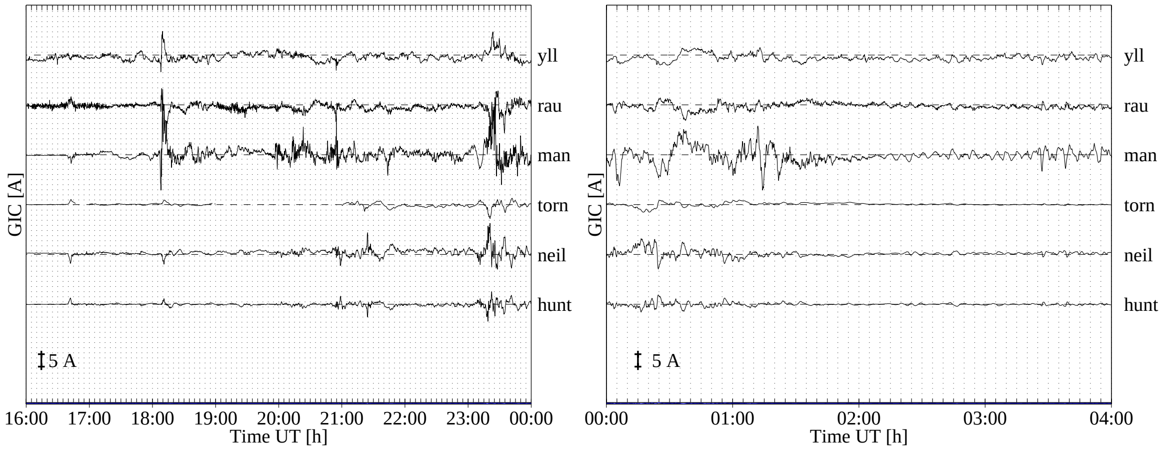

Figure 1: GIC at the Scottish and Finnish power system neutrals and at the Finnish pipeline on April 6 (left) and 7, 2000.

DRIVERS OF LARGE GIC DURING APRIL 6-7, 2000, GEOMAGNETIC STORM

On April 4, 2000, a coronal mass ejection (CME) was observed to leave the Sun. Although the ejecta was not believed to be directly Earthward, the sheath region between the shock front and the driver gas hit the Earth's magnetosphere causing the largest geomagnetic storm of 2000, as measured by the low-latitude Dst index [9]. Solar wind (magnetized) plasma conditions, namely strongly negative and fluctuating IMF and high dynamic pressure in the sheath region behind the shock produced strongly driven magnetospheric activity.

At the onset of the storm, at 16:41 UT, the geomagnetic sudden commencement (SC) produces a global enhancement of the geomagnetic field and causes the first large GIC both in UK and Finland (Fig. 1). The amplitude of GIC is 2-3 A at all the measurement locations and the enhancement of the GIC lasts about 5 minutes. The $\mathbf{E}_{sur}$ pattern shows a coherent west to south-west orientation during the SC (up to 16:40:00 - 16:41:40 UT). Around 16:42 UT $\mathbf{E}_{sur}$ in Fennoscandia adopts a more north-south orientation, but remains westerly over the UK. Thus, the first impact is quite coherent across the studied region. This is in accordance with the basic SC model of [2] in which a global magnetic signature is observed for a few minutes during the passage of the MHD wave produced by the impact of the interplanetary shock.

At 18:07 UT large enhancements of GIC are observed at the Finnish stations, the largest, at 20 A, being measured at Mäntsälä. These GIC coincide with a substorm onset that causes the intensification of the eastward electrojet and the penetration of the westward electrojet into the Fennoscandian region (Fig. 2). Only a couple of minutes after the intensifications at the Finnish stations, GIC enhancements are observed also in the UK. Prior to 18:07 UT, $\mathbf{E}_{sur}$ shows little coherence across Northern Europe. Between 18:07 and 18:09 UT a localised enhanced $\mathbf{E}_{sur}$ is observed to develop over Finland and Sweden (Fig. 3), between 50 and 60 degrees geomagnetic. Characteristic is that the orientation of the $\mathbf{E}_{sur}$ pattern changes rapidly. In the UK, $\mathbf{E}_{sur}$ is consistently westwards over this time interval, turning eastwards after 18:12 UT. Large Finnish GICs ($>$ 5 A) are observed for a period of approximately 6-7 minutes. The period corresponds roughly to the intensification of the substorm time electrojets.

During the period 19:50-22:00 UT, several GIC enhancements are seen both in the UK and in Finland. Let us concentrate on events that took place at 20:55 UT and 21:24 UT. At 20:55 UT a substorm related westward electrojet enhancement was accompanied by a very local current system in the vicinity of Nurmijärvi Geophysical Observatory. The localised current system produces GIC of 14 A at Mäntsälä. Scottish measurements are between 3 A - 4.5 A and are clearly above any background noise level. This suggests that intense current changes in the vicinity of Nurmijärvi may be embedded in some larger scale changes of ionospheric currents. GIC above 5 A are observed for one minute at Mäntsälä. At 21:24 UT GIC enhancements are observed at the UK stations. This is the only time of the entire storm period when large GIC is observed only in the UK, with no clear enhancement of GIC at Finnish stations. In terms of equivalent currents, it is the development of the westward current above the UK that drives the GIC.

At 23:15 UT a large substorm onset takes place. The initial magnetic disturbance at the Earth's surface propagates northward, which is typical character of substorms [e.g., 12]. The time derivative of the ground magnetic field behaves very irregularly and indicates that even during clearly identifiable substorm events, when the intensity of the westward electrojet sharply increases, large contributions to GIC come from the small and rapidly changing currents superimposed

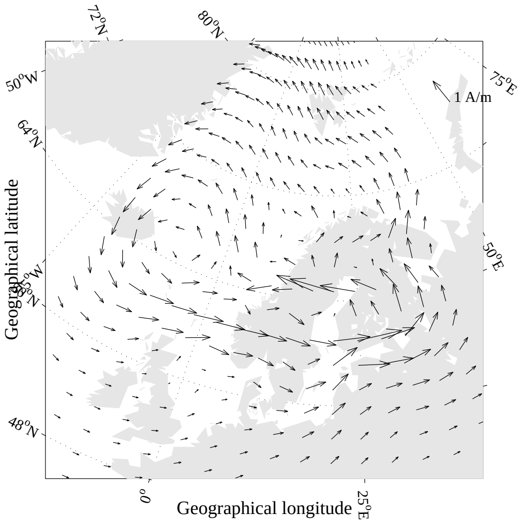

Figure 2: Ionospheric equivalent currents on April 6, 2000, at 18:09 UT.

on the electrojet. The largest GIC are observed during the expansion phase of the substorm, peak values varying between 23 A (Mäntsälä) and 5 A (Torness).

At the beginning of April 7, the geomagnetic storm has passed its main phase. Southern Finland and northern UK are under an enhanced westward electrojet. Variations of the electrojet cause large GIC in these areas throughout the period 00:00 - 01:30 UT.

During the period 02:00 - 04:30 UT, coincident with the recovery phase of the storm, geomagnetic pulsations drive GIC at all stations. A rough estimate for the period of the pulsations is 5-8 minutes, which makes them fall into the Pc5 category. Pc5 pulsations are thought to be produced by solar wind driven field line resonances that occur at higher latitudes [8]. At the very end of the storm event, an increase of GIC at all stations is observed between 03:25 - 03:55 UT, perhaps due to an increase in the amplitude of pulsations, or due to the appearance of some other current system superimposed on currents associated with the pulsations. The largest amplitude GIC (6.5 A) is observed at Mäntsälä.

DISCUSSION

Although most of the very largest GIC during the April 2000 storm were clearly related to substorm intensifications, there were no common characteristics in the substorm behaviour that could be associated with all the large GIC. For example, both very localized ionospheric current structures and relatively large scale, propagating structures were observed during individual peak GIC. Only during the sudden commencement at the beginning of the event and during the period of geomagnetic pulsations at the end of the event were there large scale coherent GIC across northern Europe. The typical duration of peak GIC was generally quite short, typically varying between 2 - 15 minutes.

In the light of the present study one key issue, related to the possibility of GIC prediction, is the predictability of substorms. For this, the time of onset and the location of ionospheric current intensifications needs to be known. If these characteristics are given with sufficient accuracy, regional GIC warnings may be given with a reliability that might be acceptable to potential space weather clients. However it is clear that, for the moment, accurate GIC predictions, where the behaviour of GIC at individual sites is computed, are not possible with present knowledge. The dynamics of ionospheric currents have been shown to be too complex for existing predictive methods to cope with.

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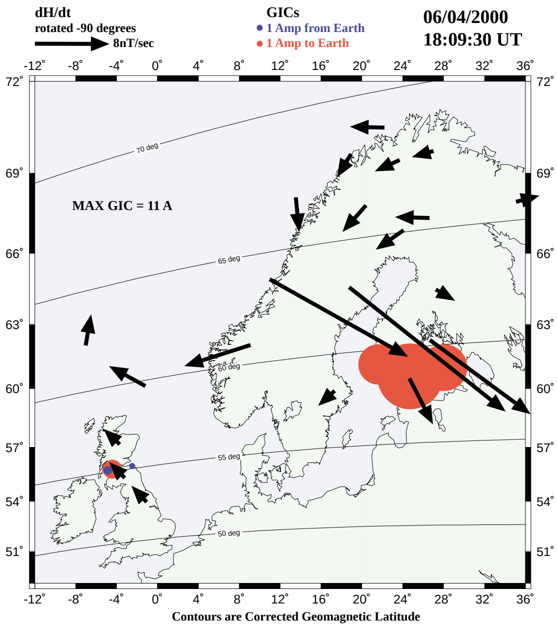

Figure 3: GIC at the Scottish and Finnish power system neutrals and at the Finnish pipeline and $d\mathbf{H}/dt$ pattern ($\mathbf{E}_{sur}$) of the geomagnetic field on ground on April 6, 2000 at 18:09 UT. Ends of arrows indicate the locations of magnetometer stations. GIC measurement locations (from west to east) are in Hunterston, Neilston, Torness (all in Scottish power system), Rauma (Finnish power system), Mäntsälä (Finnish pipeline) and Yllikkälä (Finnish power system).

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