GENERAL MECHANISMS OF GEOMAGNETICALLY INDUCED CURRENTS IN POWER SYSTEMS AND PIPELINES

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ABSTRACT

Geomagnetically induced currents (GICs) in technological conductor systems on the ground are a manifestation of space weather. The basic mechanism of the phenomenon is well understood. Ionospheric currents varying rapidly in time and space are the main cause of large GICs. The most significant events are characterised by a high global geomagnetic activity, and a necessary condition for a local occurrence of GICs are large values of the time derivative of the geomagnetic field. Due to this locality requirement, it is still very difficult to provide reliable GIC forecasts for a given system.

INTRODUCTION

Geomagnetically induced currents (GICs) in ground-based technological conductor systems provide an excellent challenge for testing space weather models, since the full understanding of the phenomenon requires the inclusion of the whole interaction chain from the Sun down to the Earth's surface. GICs can be determined if the spatiotemporal behaviour of ionospheric currents is known and models of the Earth's conductivity are available. Then it is in principle possible to solve the horizontal geoelectric field, which drives GICs. If the electric field is known it is a relatively straightforward DC problem to compute GICs in discretely (power networks [6]) and continuously grounded systems (buried pipelines [9]). The real scientific challenge is to calculate the electric field reasonably accurately and fast.

GIC in a given conductor system is closely related to the time derivative of the magnetic field measured at a nearby location. More quantitatively, the derivative of the horizontal field ($d\mathbf{H}/dt$) yields a sufficient information [13]. This provides a pragmatic tool for deriving statistical predictions of the occurrence of GICs using the measured geomagnetic field. Together with simplified models of the ground conductivity, a plane wave assumption results in easy calculations of the geoelectric field [8]. It is also possible to derive a direct relation between magnetic variations and GIC [11]. These approaches do not require any deeper understanding of near-space phenomena beyond GIC.

A recent achievement combines a method to derive equivalent ionospheric currents from ground magnetic field recordings [1] to a fast computation technique of the surface fields which allows for the use of multilayered earth models [7]. This could be efficiently used for nowcasting purposes too. Forecasting GICs early enough before a large geomagnetic event is much more difficult. One reason is that only extreme cases seem to be significant from the industrial viewpoint, and the characteristics of such events are still quite unknown.

One of the few operative GIC forecasting systems is provided by [4]. Starting from solar wind observations by the ACE satellite it utilises statistical models to deduce large-scale ionospheric currents. The geoelectric field is then determined, GICs are calculated in a given power network, and effects on the system are evaluated. In principle this is an ideal system, since it can provide advance warnings at least 30 minutes before solar wind disturbances hit the magnetosphere. This procedure may yield a reasonable hint of a forecoming higher geomagnetic activity. However, it is hardly possible yet to derive reliable predictions of the accurate location and time of large GICs.

SPATIOTEMPORAL SCALES OF GEOMAGNETICALLY INDUCED CURRENTS

Spatial scales of large GIC events vary from very local to global ones [12]. Examples of the former are rapid auroral activations, whose spatial extents can be only about 100 km [5]. In turn, sudden impulses due to solar wind pressure pulses are clearly global events [2]. A necessary requirement for significant GICs is a large time derivative of the ground magnetic field (up to a few 10 nT/s). The duration of geomagnetic storms can be some days, but continuous sequences with rapid magnetic field variations typically last a few minutes only.

There can be several totally different ionospheric current systems responsible for GICs during a single storm. A recent extreme event occurred on November 6, 2001 (Fig. 1). The storm started with an expectionally strong SSC followed by a mixture of a very intense westward electrojet and pulsations. An equally large GIC day was November 24, 2001, when GIC in the Finnish natural gas pipeline reached equally large values as on November 6. During the November 24

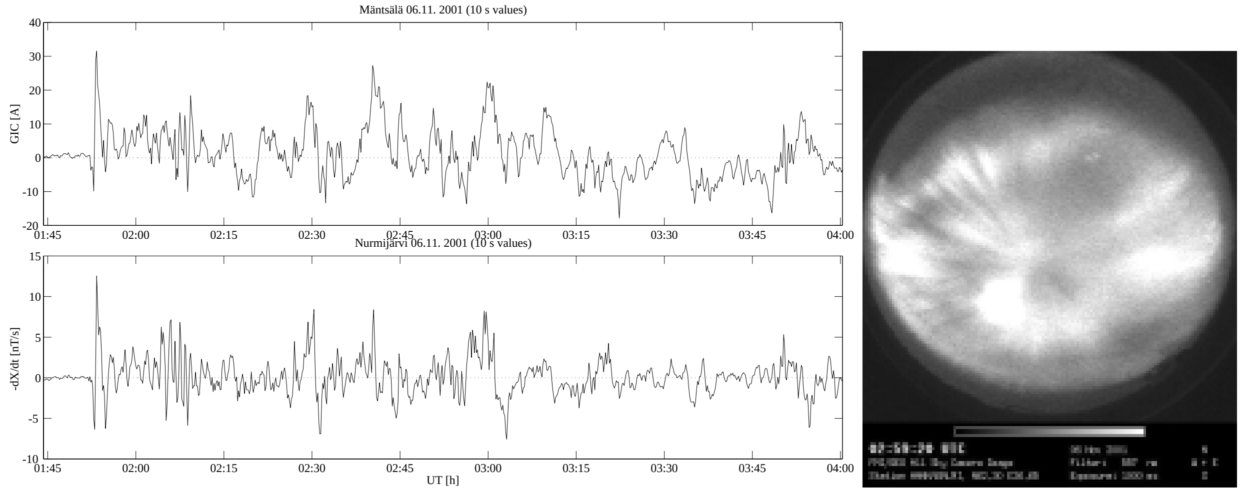

Figure 1: Left, top panel: Geomagnetically induced current in the Finnish natural gas pipeline in southern Finland on November 6, 2001 after an intense sudden storm commencement at 01:53 UT. Left, lower panel: Time derivative of the northward magnetic field at the nearby Nurmijärvi Geophysical Observatory (60.50 N, 24.65 E). Right: Auroral all-sky image at Hankasalmi, central Finland (62.30 N, 26.65 E), on 02:59:20 UT. The brightness of auroras is emphasized by the fact that there were some clouds and full moon (seen near the middle of the image).

event, one of the largest values of $d\mathbf{H}/dt$ was measured in northern Fennoscandia (Fig. 2). The maximum occurred at a moment when a strong eastward ionospheric current decreased rapidly and also changed its direction. It is noteworthy that the peak time of the storm took place in late morning (after 09 local time), because typically large GIC values are concentrated around the local midnight.

Inspection of GIC events in the Finnish natural gas pipeline in 1999-2002 indicates that a high geomagnetic activity is a necessary condition for large GIC values. For example, 19 of the 20 most active days defined by the maximum of GIC are classified at least in the category of major storms (A_k index at the nearby Nurmijärvi observatory larger than 50). Consequently, extreme GIC events generally require a high global activity as a ”background”. However, the present physical knowledge is insufficient to predict the exact locations of activations relevant to GIC (i.e. the sites where large $d\mathbf{H}/dt$ can be expected).

FUTURE INVESTIGATIONS

An urgent task is to derive a quantitative classification of ionospheric current systems which produce large GICs. Unless such a research is done, forecasting may remain useless in practice with too many false alarms. It follows that a physics-based forecasting model is very demanding. The aim should be to predict the ground magnetic variation field, from which it is possible to calculate GICs. The required temporal accuracy is one minute or less and the field should be known in a grid with a cell size of 100 km x 100 km or smaller. We emphasize that for GIC purposes the time derivative of the magnetic field should be known accurately, as well as the region where the event occurs. Physical models are scientifically preferable, but it may take more than one solar cycle before any really operational tools are available. Alternative approaches, which may become useful more quickly, are neural networks and (non-)linear techniques [10]. One idea mixing different approaches could be to forecast the occurrence of specific types of events that are known to cause large GICs.

SUMMARY

GICs can cause harmful effects on various man-made systems [3], so GIC studies are often justified by the potential space weather risk. However, there are only few very serious publicly known failures, like the March 1989 power system blackout in Canada. So the danger of ground effects should not be exaggerated. On the other hand, large GIC events are often interesting due to space physical aspects. GIC is also an interesting phenomenon for a scientist and consequently worth studying as such.

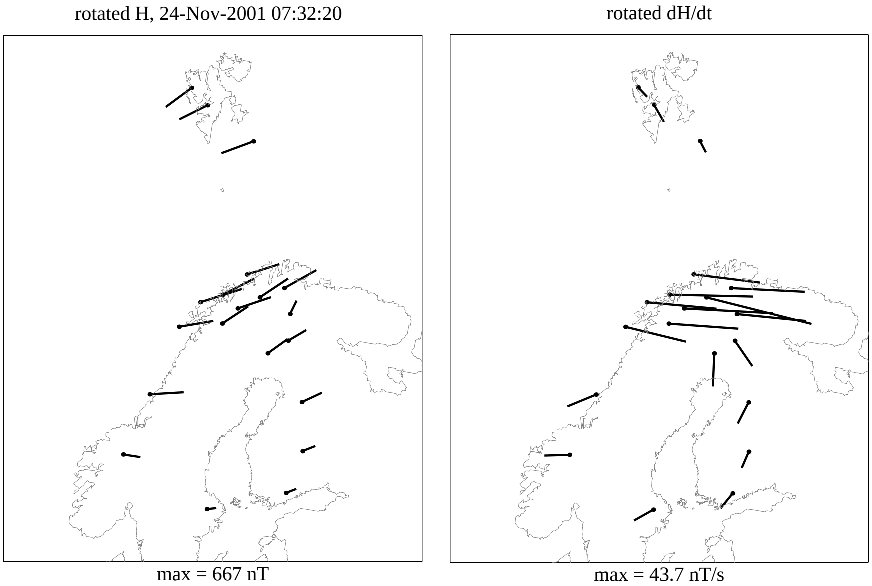

Figure 2: Left panel: Geomagnetic horizontal variation field on November 24, 2001, 07:32:20 UT, at the IMAGE magnetometer stations. Vectors are rotated 90 degrees clockwise to mimic the overhead ionospheric currents. Right panel: The simultaneous time derivative of horizontal variation field. Vectors are rotated 90 degrees anticlockwise to mimic the geoelectric field at the earth's surface.

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