A REVIEW OF THE EFFECTS OF SPACE WEATHER ON GROUND-BASED TECHNOLOGY

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ABSTRACT

Important sectors of ground-based technology affected by space weather are: geomagnetic surveys for geological interpretation; directional drilling surveying high voltage power transmission grids; active cathodic protection against corrosion of pipelines; long distance telecommunication cables; and possibly railway signalling. (For the purpose of this paper sub-ionospheric radio propagation and satellite positioning systems such as GPS or Galileo are not considered as ground-based technology.) The first two sectors are primarily concerned with direct interference on magnetic measurements, the last three with effects arising from induced electric fields. In this paper we review the effects in each of these sectors, and discuss services which have been designed to assist operators in some of these fields to manage the risks associated with space weather.

1. INTRODUCTION

This paper presents a brief review of the effects of space weather on ground-based technology. It does not include the effects experienced by satellite and avionic systems, nor does it include the effects on radio propagation for communications or satellite navigation, both of which topics are reviewed elsewhere in these proceedings.

Comprehensive reviews of the effects of space weather have been carried out by the teams performing the study on a space weather programme for ESA [1], [2], [3], and here we examine those effects identified with ground-based technology.

There is a broad distinction between two classes of affected technology: those effects related directly to variations in the geomagnetic field; and effects related to electric fields or currents induced by geomagnetic variations. These processes are considered in the next two sections.

2. DIRECT EFFECTS OF GEOMAGNETIC VARIATIONS

The two main technologies affected directly by geomagnetic variations are geophysical surveying and directional drilling.

2.1 Geophysical surveying

In geophysical surveying it is common to make surveys of the geomagnetic field intensity, and to express the difference between the observed value and a notional value of the core-generated field as the "magnetic anomaly" field, which may aid in interpretation of subterranean structure and composition. Surveys over small areas on land may be made on foot, but larger areas, particularly offshore, are made by aircraft or ships. The observed magnetic field intensity also includes a component originating from ionospheric and magnetospheric, or "external", magnetic fields. Over a small area on land the effects of the time dependent external field can be removed by running a magnetometer at a base station, and subtracting the observed time variations from the survey data. This is relatively easy on land and for areas up to a few tens of km in size. However, if the survey area is a long way offshore the base station data may not be representative of the external field variations in the survey area. When flying an aeromagnetic survey a typical rule of thumb is to re-fly any survey line during which the magnetic field changed by more than 5nT in 5 minutes at the base station. There is a cost implication in having to re-fly survey lines, and reliable forecasts of geomagnetic activity could thus be of use in planning survey operations.

It should be noted that the severity of the effects of magnetic storms is latitude dependent, and that surveys in areas near the auroral oval are much more affected than surveys at low latitude. We also note that the use of gradiometer techniques can filter out the effects of external fields, removing the need for knowledge of external field variations, although the resulting data require different interpretation.

2.2 Directional drilling

Directional drilling is a technique developed in the oil industry to extract the maximum amount of reserves from an oil field from one rig by drilling to targets around the rig, reaching up to as far as 11 km horizontally. A full description of this application of space weather services is given in these proceedings [4].

We note here that the industry's requirements are met by a near real-time monitoring service rather than a forecast service, although reliable forecasts may be of some value to the well-bore surveyors in planning survey measurements during drilling operations. This application is also latitude dependent, and is unlikely to be of great importance at geomagnetic latitudes lower than about 50°, except perhaps where knowledge of the total field intensity is required in a location close to the equatorial electrojet.

3. EFFECTS OF INDUCED ELECTRIC FIELDS

Induced electric fields and currents can adversely affect the normal operation of high voltage power transmission grids, active cathodic protection of pipelines, telecommunication cables and, possibly, railway signalling.

3.1 Power grids

The problem of geomagnetically induced currents flowing in high voltage transformers has been recognised since at least the early 1980s, but was brought into stark relief by the widespread failure of the Hydro-Quebec power grid resulting from the geomagnetic storm on 13/14 March 1989 [5]. The main problem occurs when quasi-DC geomagnetically induced currents (GIC) flow between the high voltage lines and the earth through transformer windings. The GIC can saturate the transformers reducing efficiency dramatically, perhaps damaging the transformer or triggering safety systems that remove the transformer from the circuit, possibly creating knock-on effects in the rest of the grid. The March 1989 event stimulated research into improving the modelling of GICs, eg. [6], [7], and the setting up of magnetic storm prediction services for the electricity industry. There are a number of examples of services developed specially for electricity utilities ranging from simple provision of a forecast [5], through provision of forecasts and near real-time data [8], to the use of L1 monitor data to provide continuous prediction of GIC up to 30 minutes ahead [9].

Predictions of geomagnetic activity are useful on two timescales. A forecast up to three days ahead, based on solar observations, allows planners to schedule generating plant so that spare capacity will be available in the event of a major geomagnetic disturbance. Forecasts based on solar wind observations at L1 provide a warning up to about 30 minutes ahead of a severe magnetic disturbance, and this allows control room operators to implement procedures for managing the GIC threat.

The severity of the effects on power grids depends in part on the latitude of the grid, and on the underlying and surrounding land or sea conductivity. An example of the type of modelling that can be used to estimate the induced surface electric field which drives GICs in the Scottish power grid is given in [8]. A further issue for research is the effect of long term wear on transformers which have been exposed to saturating GIC over many years.

One of the most important factors determining the effects of GIC on a transmission system is transformer design, and here space weather models can play an important role in specifying design parameters.

3.2 Pipelines

Pipelines, particularly those that are buried or under water, are often protected from corrosion by maintaining them at a negative electrical potential with respect to the ground. During a magnetic storm the electric field induced along the pipeline may counteract the applied potential, removing the corrosion protection and possibly even accelerating corrosion [10,11]. Although this is a clear effect of space weather, the solution to the problem lies more with engineering the active protection to cope with the most severe magnetic storms expected, rather than relying on a space weather prediction service. Space weather models may help in determining and specifying these design parameters. Reliable forecasts of geomagnetic activity may still be useful in planning service schedules when testing may be disrupted by geomagnetic activity.

3.3 Telecommunication cables

Long distance telecommunication cables were probably the first human technology to be affected by space weather, when it was realised in the mid 19^{th} century that "anomalous currents" could sometimes flow in telegraph cables [12]. In more recent times the operation of a transatlantic cable was severely affected during the magnetic storm of 13/14 March 1989 [12] Now that most long-distance telecommunication cables consist of optical fibres rather than wires, the direct effects of geomagnetically induced electric field may be less important than they used to be. However the power supply to signal amplifiers along the length of the cable must be designed to cope with geomagnetically induced electric fields, and space weather models will be important for determining and specifying design parameters.

3.4 Railway signalling

It has been suggested that electric fields induced in railway signalling systems can be responsible for malfunctioning of the system. However there is only one such case reported in 1982 [1], [2]. It is clear that the issue here is one of designing systems to be robust in the presence of geomagnetically induced electric fields, and that if, on rare occasions, a signalling system should fail due to geomagnetic induction effects, it should fail in a safe mode. Space weather models may be of value in specifying system parameters during the design phase.

4. CONCLUSIONS

The varied effects of space weather on ground-based technology have been presented. Of these, the operation of high voltage power transmission grids would benefit most from a space weather service consisting of the provision of real-time measurements of the space environment combined with detailed modelling and prediction of the flow of GICs.

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