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EFFECTS OF GEOMAGNETIC STORMS ON MAN-MADE SYSTEMS IN BOREAL/AURORAL REGIONS, PARTICULARLY ON COMMUNICATION AND POWER TRANSMISSION SYSTEMS

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During recent years boreal regions have experienced ever increasing development due to energy reclamation projects, the construction of oil/gas-pipelines, high-energy hydro electric generation plants, EHV power transmission systems, and communication systems. The convergence of the earth's magnetic field above these regions dictates the relatively high ionospheric and magnetospheric energy densities in the auroral zone. Solar storms reach out to the earth and couple energy into the magnetosphere and ionosphere. These storms, and substorms due to stored energy in the magnetosphere produce dramatic changes in electrojet currents and auroral activity, and also produce significant variations of the geomagnetic fields and magneto-telluric currents. These changes in turn interact with natural and man-made systems on the earth's surface - the interaction becoming stronger the closer we approach and penetrate the auroral zone (52° to 62° latitudes in our central Canadian Prairie regions). Thus, during periods of high sun-spot activity which cause substantial changes of the earth's magnetic field, system disturbances due to geomagnetically induced currents in man-made systems occur [1]. For example, magneto-telluric currents induced along the conducting pipes of oil/gas-pipelines have led to increased corrosion or weakening of welding joints; geomagnetically induced currents in electric power generation/transformation/transmission/distribution systems have caused serious damages to transformers, tripping of protection relays, and phase imbalancing; and radio-tele-communication in various specific frequency bands are heavily interrupted due to radio noise, etc. [2]. In addition, it has been found that the earth's conductivity increases appreciably after geomagnetic storms which in turn affects man-made systems. Similarly, there seems to be an increase of overall global electric storm activities associated with geomagnetic storms which not only affects the weather but also electric transmission systems [3].

Conversely, very recently it has been found that natural and man-made signals, generated close to or within the auroral zone, strongly interact with the magnetosphere. For example, harmonics of the fundamental AC frequency radiated from electric power lines close to the auroral belt into the magnetosphere could cause serious after-effects on energy exchanges between the ionosphere and the magnetosphere [4], which may lead to latitudal relocation of the auroral electrojet currents. In addition, the AC/DC-HV transmission systems of over 500 km in length could serve as effective radiation sources of VLF signals or could be effectively used as VLF receiving antenna systems.

Effects on Power Transmission

Our main objective in the study of the effects of solar magnetic storms on the transmission of power is to determine the expected number of significant storms, over a 11 year period of sunspot activity, that interfere with the operation of Manitoba Hydro's power system, or interfere with communications when power lines radiate, and subsequently produce economic losses. We have initiated a study of transformer neutral-to-ground current data and corresponding IMS magnetograms (Walker [5]) and permanent Canadian magnetic field observatory data obtained during storms or substorms. Data have been analyzed for a strong substorm on 21 September 1977, and an analysis is in progress for a storm on 4 January 1978. Our analysis shows that modelling the induction process in power lines will require more understanding of the effects of the spatial variation of the inducing fields over the power system network. The usual circulating currents in the earth enter the power systems through ground points in the neutrals of transformers. It has also been proposed by ourselves and Kisabeth that non-circulating, oscillatory currents directly induced in the transmission lines can be appreciable (∿280A), if the gound points act as charge sources or sinks.

The analysis of the 21 September 1977 substorm indicates the approach we are using in developing our induction model. The magnetograms from Thompson, Lynn Lake, and Whiteshell cover most of the area over which the power lines extend and represent the scale of the field by similarities in their variation. In this summary we have included the Z-field magnetograms to show the inversion of the field between Lynn Lake and Whiteshell. This inversion indicates a source between these stations. Through the analysis we also wanted to establish a strong correlation between the frequency of the rate of change in surface magnetic field variations and the frequency of the observed currents. We have computed the power spectra of the induced current records from La Verendrye station near Winnipeg and the magnetograms from the Whiteshell (IMS) observatory. The induction model developed by Price [6], for periodic field variations, a layered earth, and source scale has been used to estimate the corresponding north-south and east-west electric fields. The power spectra for the induced current shows a strong variation with a period of 20 minutes. The spectrum for the rate of change of the Z-field component at Whiteshell, which is closest to the east-west power lines, shows a strong peak with period of 5 minutes. Similarly, the largest peak in the X-field component has the same period. Using a single layered earth model (ρ_1=100Ω-m, 10km thick; ρ_2=250Ωm) we obtain a surface electric field E_y=0.02 V/km. To compare this with the power line voltage gradient we consider a three phase line (230KV-AC) of resistance 0.002 Ω/km. For a peak current of 25A, and this line resistance, we obtain a gradient of 0.05 V/km. It seems to us that an aperiodic analysis would be more appropriate when the nature of the magnetic fields is considered. Indeed, the periodic analysis suppresses the larger rates of change (up to 120 γ/min.) that can be obtained directly from the magnetograms. However, the strong periodic behaviour of the induced current is clear in the La Verendrye record. This comparison suggests that there is a mechanism that selects energy from the spatial/temporal variations of the magnetic fields and enhances the integrated (over the extent of power network) electric field variation at particular frequencies. These results also indicate that the regular measurement of magnetic fields would be more useful in this type of study and modelling of electrojets, if the smoothed larger scale telluric fields were also measured, as suggested by Campbell [7].

We are very much interested in the inverse problem, where the currents in the auroral electrojet are determined from observations at the ground level. Albertson [8] has considered an E-W electrojet line-current model to obtain a range of surface fields 0.76 V/km to 1.52 V/km, with an electrojet of magnitude 10^5A and period of 6 minutes. On the basis of this model a current of ∿4000A (E-W) would produce the periodic components of the X-field at Whiteshell for the similar period of 5 minutes. A N-S current of ∿1000A is required to give the observed Y-field. A model developed by Kisabeth and Rostoker [9] shows that these Birkeland currents can produce flux densities of about 300γ, which is comparable to the periodic flux density obtained by Albertson in his analysis [8]. The majority of storms do produce N-S currents in the transmission lines as indicated by the records from Grand Rapids, which is connected to primarily N-S lines. This aspect of modelling is becoming well developed, hence we see that in the near future very useful models for this inverse problem will be available.

The primary result of our work at this stage of our study is the establishment of the need for a fuller understanding of induction of currents in power lines, or similar conducting anomalies, and the determination of the aspects of induction that need to be included in a more complete model of the systems involved. The most important aspects of this induction may be the magnetic field spatial variations and the energy coupling between the source and the power lines.

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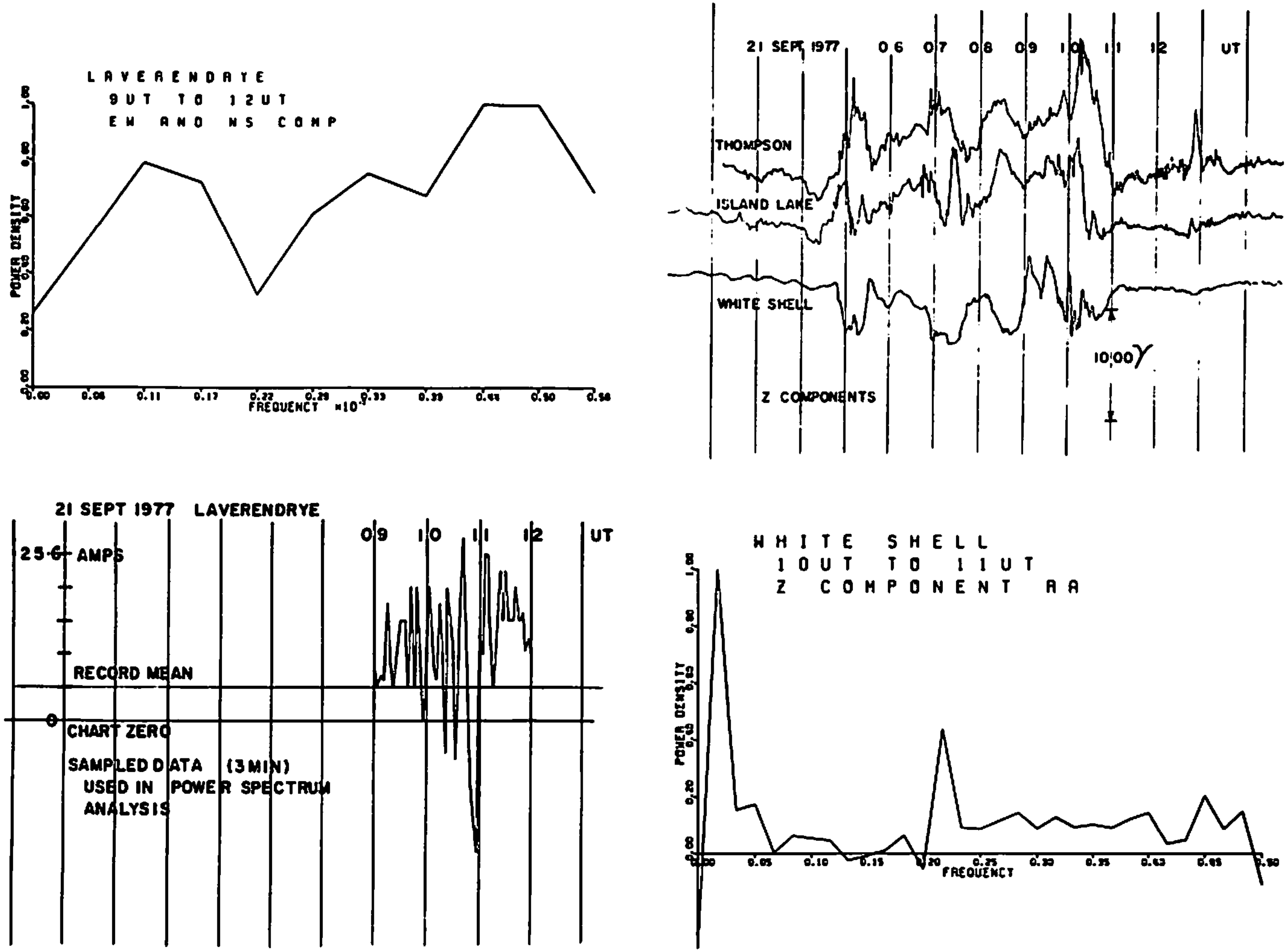

Fig. 1 Processed Data of 21 Sept. 1977 geomagnetic substorm along 96° 30' longitude in Manitoba, Canada.