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Study of Geomagnetically Induced Current from Time Derivative of the Earth's Magnetic Field

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Abstract

One of negative impacts of space weather on technological systems is the occurrence in conducting ground systems (electric power systems, pipelines) of geomagnetically induced current (GICs) caused by variations of the geomagnetic field during large magnetic storms. Analysis of variations of the horizontal component (***H***) of the geomagnetic field and its time derivative (*d**H**/dt*) for seven periods of high magnetic activity in 2003-2005 is carried out using data from magnetic observatories Alma-Ata, Novosibirsk and Irkutsk. Distributions of directions of ***H*** and *d**H**/dt* are derived. It is shown that the large *d**H**/dt* determining significant GICs are caused by variations of a magnetic field of three types: a sudden pulse (SI) observed in the beginning of a magnetic storm, pulsations, and casual variations of the field during a magnetic storm.

1. Introduction

During large magnetic storms, variations of geomagnetic field induce currents in the Earth's surface called geomagnetically induced currents. Different regions of the Earth have different conductivity. Igneous rocks do not conduct electricity very well so the currents tend to take the path of least resistance and flow through man-made conductors that are present on the surface. During large magnetic storms, these GICs can cause serious problems for the operation of the power systems, disrupting the operation of transformers and other facilities. Greatest GICs problems occurred at power systems located at high latitudes due to their proximity to dynamic auroral electrojets; therefore, the majority of studies were carried out in the high latitudes. However, recently Koen and Gaunt (2002) showed that GICs are present even at the mid-latitudes during strong geomagnetic storms. Moreover, Kappenman (2003) showed that global burst in intensity of the geomagnetic field (the sudden beginning of a magnetic storm) can be a reason of significant GICs at all geomagnetic latitudes including equatorial ones.

Therefore, the GICs problem is actual for Kazakhstan where a network of high-voltage (220–1150 kV) power electric lines of general extent of 27 000 km operates. The aim of the present work is studying a possibility of occurrence of significant GICs in this region using measurements of variations of the horizontal component of the geomagnetic field at magnetic observatories of Alma-Ata, Novosibirsk and Irkutsk whose geomagnetic latitudes are close to geomagnetic latitudes of southern and northern borders of Kazakhstan.

2. Method of Data Analysis

There are several methods of GICs study. The most common method is based on linear dependence between GIC and time derivative of the horizontal component of the magnetic field (dH/dt) as Faraday's law states. Validity of the method has been confirmed by Bolduc *et al.* (2000) where results of simultaneous measurements of variations of the geoelectric field and dH/dt of the magnetic field orthogonal to the electric field were compared. The further acknowledgement of reliability of this method has been obtained by Viljanen (1998). Here, direct measurements of GICs at high-voltage transformers in power electric lines were carried out. Changes of the northern component of the geomagnetic field (H_x) generate the east component (E_y) of an electric field; therefore, measurements of dH_x/dt give E_y, and measurements of dH_y/dt are used for calculation of E_x. The current generally induced in a power system is expected to be:

$$GIC = c(aE_x + bE_y), \tag{1}$$

where a and b depend on the geometry of the power line and its resistance. The coefficient c is used to equalize theoretical and observed GICs. For the Finnish power grid whose extent is not so large, the values of a and b have been 10 and 94 A·km/V, respectively, (strength of electric field in expression (1) is given in V/km). It is obvious that for Kazakhstan with its extended electric power lines, the values of multipliers a and b should exceed Finnish ones.

In order to estimate the rate of change of the horizontal component of the geomagnetic field we used the data of three magnetic observatories. The southern part of Kazakhstan was provided with the data of the observatory Alma-Ata (code AAA, geographical coordinates: 43.25N, 76.92E, geomagnetic coordinates: 34.13N, 152.62E).

Northern part of Kazakhstan was provided with the data of the observatory Novosibirsk (NVS, geographical coordinates: 54.85N, 83.23E, geomagnetic coordinates: 45.39N, 159.41E) and the observatory Irkutsk (IRK, geographical coordinates: 52.17N, 104.45E, geomagnetic coordinates: 41.73N, 176.73E). For the present study we used one-minute data of the northern (H_x) and eastern (H_y) components of the geomagnetic field of observatories Alma-Ata and Novosibirsk and the horizontal component ($\boldsymbol{H}$) and declinations D of the observatory Irkutsk. To provide the field components variations their base-lines were subtracted from the primary data. Further, under $\boldsymbol{H}$ we shall understand variations of the horizontal component. The time derivative ($d\boldsymbol{H}/dt$) was calculated as ($\boldsymbol{H}_{t+1\ \mathrm{min}} - \boldsymbol{H}_t$)/1 min. Variations of northern and eastern components are designated as X and Y, respectively.

3. Variations of the Geomagnetic Field and its Derivative

Present analysis includes seven periods of the high magnetic activity occurred in 2003-2005. In Fig. 1 variations of the northern component and its derivative (dX/dt) for three observatories at magnetoactive periods are presented.

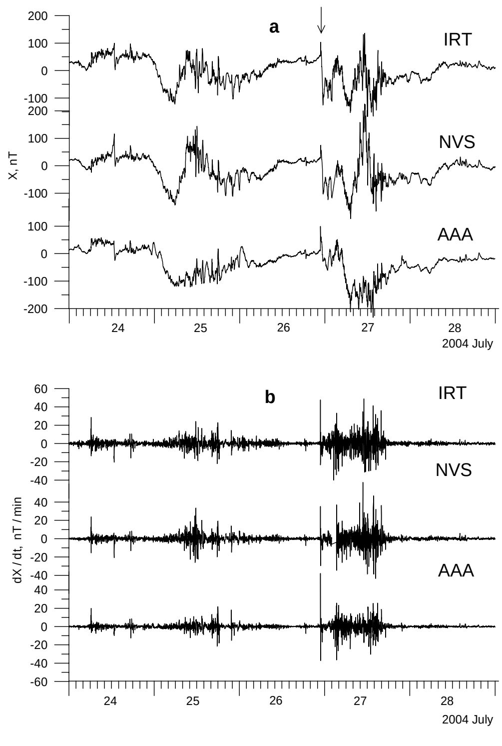

Fig. 1. Variations of the northern component (a) and its derivative (dX/dt) (b) for two successive large magnetic storms.

The analyzed period includes two successive large magnetic storms during which substantial intensification of the dX/dt was observed. It is evident that dX/dt for Irkutsk and Novosibirsk is larger in comparison with Alma-Ata. The second storm began from a strong sudden pulse (SI) at all three stations at 22:28 UT (pointed by the arrow). The burst in *dX*/*dt* occurred practically simultaneously at all three observatories and its amplitude was maximal at the southern station. Dates, time and amplitudes of *dX*/*dt* bursts occurred synchronously at observatories Alma-Ata and Novosibirsk are presented in Table 1. Three of the bursts (26.07.04, 07.11.04 and 09.11.04) are connected with SI which preceded the beginning of large magnetic storms. In all these cases the *dX*/*dt* magnitude in Alma-Ata exceeded the values observed in Novosibirsk. Several successive significant *dX*/*dt* bursts not connected with SI were observed on the recovery phase of very large storm occurred on 31.10.03 at 02:24 UT. Amplitudes of the biggest bursts are presented in the table. These bursts have been caused by periodic pulsations of the geomagnetic field with the average period of 7.2 minutes. In this case, amplitudes of bursts in Novosibirsk exceeded amplitudes of Alma-Ata. Detailed global pattern of Pc5 geomagnetic pulsation for this storm was presented by Kleimenova and Kozyreva (2005).

Table 1

Time and amplitudes of *dX*/*dt* bursts

Date	UT	*dX*/*dt* [nT/min]		Type of disturbances
		Alma-Ata	Novosibirsk	
31.10.03	02.10 – 02.30	105	252	Pulsations
31.10.03	05.30 – 05.55	75	155	Pulsations
31.10.03	10.25 – 10.55	85	80	Pulsations
26.07.04	22.28	59	37	SI
07.11.04	18.31	65	60	SI
09.11.04	18.52	78	54	SI

It is known that rotation of $d\boldsymbol{H}/dt$ by 90^{o} anticlockwise gives the direction of the horizontal electric field at the Earth's surface. In order to estimate the possible strength and direction of GICs, we calculated $|d\boldsymbol{H}/dt|$ distributions and direction distributions of $\boldsymbol{H}$ and $d\boldsymbol{H}/dt$ for the cases considered with the condition $|d\boldsymbol{H}/dt| > 5$ nT/min. In Fig. 2 these values are plotted for storms presented in Fig. 1. For better presentation the $\boldsymbol{H}$ and d**H**/dt distributions are normalized at each subplot. The condition $|d\boldsymbol{H}/dt| >$ 5 nT/min was used by Koen and Gaunt (2002) as a threshold determining the occurrence GICs in power systems. The most interesting features of plots in Fig. 2 are the narrow **H** distributions for all observatories and the narrow $d\boldsymbol{H}/dt$ distribution for Alma-Ata, extended in the geomagnetic north–south direction and scattered $d\boldsymbol{H}/dt$ distributions for Novosibirsk and Irkutsk.

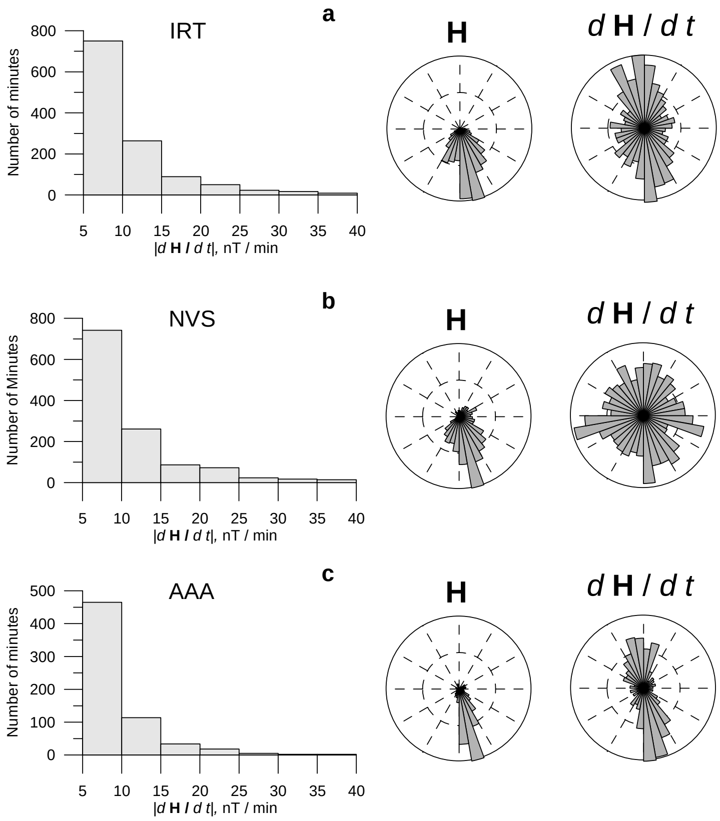

Fig. 2. $|d\boldsymbol{H}/dt|$ distributions and direction distributions of $\boldsymbol{H}$ and $d\boldsymbol{H}/dt$ for the cases considered under the condition $|d\boldsymbol{H}/dt| > 5$ nT/min.

Table 2

Total time when $|d\boldsymbol{H}/dt| > 30$ nT/min

Date	K_p	Total time with $\lvert d\boldsymbol{H}/dt\rvert >$ 30 nT/min	
		Alma-Ata	Novosibirsk
29-31 October 2003	9	148	445
22-23 January 2004	7+	0	0
24-28 July2004	8	5	56
7-10 November 2004	9-	8	78
7-8 January 2005	8-	0	0
16-19 January 2005	8-	3	6
21-22 January 2005	8	12	26

Koen and Gaunt (2002) carried out ***dH***/*dt* measurements simultaneously with GICs records in the South African power grid. Comparison of the GICs and ***dH***/*dt* values has shown that when |***dH***/*dt*| > 30 nT/min, the induced current causing undesirable consequences in power grids has arisen. We have taken the same value as a threshold for definition of total time of existence in power grids of Kazakhstan of the appreciable induced currents. Table 2 presents total time (minutes) when |***dH***/*dt*| > 30 nT/min. The data show that during strong storms (on October, 29-31, 2003, on July, 25-27, 2004, on November, 7-10, 2004, on January, 21-22, 2005) power grids, in particular at the north of Kazakhstan, can undergo to the appreciable overloads caused by GICs.

4. Conclusion

Variations of the geomagnetic field during large magnetic storms induce an electric field which induces electric current (GICs) in the high voltage transmission lines. Basically, GICs are a problem of auroral latitudes but during large magnetic storms GICs can appear at all latitudes. In the present work, the analysis of variations of ***H*** and ***dH***/*dt* for seven periods of the high magnetic activity in 2003-2005 is carried out. Distributions of directions ***H*** and ***dH***/*dt* are calculated; the most interesting property of distributions was narrow distributions ***H*** and ***dH***/*dt* for Alma-Ata, extended in the geomagnetic north-south direction and scattered ***dH***/*dt* distributions for Novosibirsk and Irkutsk. It is shown that the large *dH*/*dt* are caused by the geomagnetic field variations of three types: a sudden pulse (SI) observed in the beginning of a magnetic storm, pulsations of the magnetic field at the phase of recovery, and casual variations of the field during a magnetic storm. It is shown that during strong storms, power grids, in particular in the north of Kazakhstan, can be subjected to the appreciable overloads caused by GICs.

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