"Physics of Auroral Phenomena", Proc. XLI Annual Seminar, Apatity, pp. 26-29, 2018

Polar Geophysical Institute

DOI: 10.25702/KSC.2588-0039.2018.41.26-29

IRREGULAR GEOMAGNETIC DISTURBANCES EMBEDDED INTO SUBSTORMS AS A CAUSE OF INDUCED CURRENTS IN ELECTRIC POWER LINES

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Abstract. Influence of impulsive magnetosphere disturbances such irregular Pi3 pulsations embedded into substorms on geomagnetically induced currents (GIC) has been considered for the geomagnetic storm 27-29 June 2013. GIC were registered in electric power lines of Kola Peninsula and Karelia by the system of Polar Geophysical Institute and Kola Scientific Center. Geomagnetic field variability was examined using data from the IMAGE magnetometer array. We have confirmed that during the considered impulsive events the ionospheric currents fluctuate in both the East-West and North-South directions, and they do induce GIC in latitudinally extended electric power line. Contrary to classic point of view it is found for some events that noticeable GIC can better correlate with geomagnetic field variations B than with its derivate dB/dt. A relative contribution into GIC variations by temporal variations of the geomagnetic field and by spatial variations of the vortex-like ionosphere current structures has been examined.

1. Introduction

One of the most significant factors of space weather for terrestrial technological systems is geomagnetically induced currents (GICs) in conductor systems caused by abrupt changes of the geomagnetic field [*Lanzerotti*, 2001]. GICs associated with great magnetic disturbances were found to be dangerous for various technological systems, causing malfunction of railway equipment, disruption of ground and transatlantic communication cables, deleterious impacts on telephone lines, and reduction of the lifetime of pipelines [*Pirjola et al.*, 2005].

GIC are often modeled as fluctuations of intensity of the East-West auroral electrojet producing telluric currents in the longitudinal direction [*Boteler et al.*, 1998]. On the basis of these notions, it is commonly supposed that geomagnetic disturbances are most dangerous for technological systems (like power lines, and oil/gas pipe lines) extended in the longitudinal direction. However, it was found that fast small-scale ionospheric current structures can provide a significant contribution to rapid geomagnetic field variations, responsible for GIC generation [*Viljanen et al.*, 2001; *Belakhovsky et al., 2018; Belakhovsky et al., 2017*]. Thus, to characterize the geomagnetic field variability one needs finer characteristics than the widely used time derivative of the *X*-component (North-South) of the geomagnetic field d*X*/dt. It is still tempting to find an adequate tool to reveal the temporal-spatial features of geomagnetic field variations most relevant to the GIC generation.

Here we consider the contribution of geomagnetic disturbances to the rapid growth of the GIC in electric power lines of Kola Peninsula and Karelia for the 27-29 June 2013 geomagnetic storm. During this event the GIC reach the maximum value for the whole history of observations in this registration system.

2. Data and methods

A system to monitor the impact of GIC on power lines was deployed in 2010 in the Kola Peninsula and Karelia by the Polar Geophysical Institute and the Center for Physical and Technical Problems of North's Energetic. The system consists of 4 stations at 330 kV power line and a station at the 110 kV power line. Each station records a quasi-DC current in the dead-grounded neutral of the transformer.

The variations of the geomagnetic field were measured by IMAGE magnetometers with 10-sec time resolution. For an array of magnetometers oriented along a geomagnetic meridian, the vector diagram method can be applied. The Finnish Meteorological Institute provides the online (*http://space.fmi.fi/image/beta/*) capability to compute and visualize 2D ionospheric equivalent current vectors from the IMAGE magnetometers. For the equivalent current modeling, the method of spherical elementary current systems has been used [*Amm & Viljanen*, 1999]. The method is based on the fact that the horizontal ionospheric currents can be divided into divergence-free and curl-free components. The curl-free horizontal currents close the field-aligned currents linking the upper atmosphere with magnetospheric processes. The technique determines the divergence-free component of the equivalent ionospheric currents (which roughly describes the distribution of ionospheric Hall currents) from ground-based magnetometer data.

3. GIC event induced by Pi3 pulsations on 28-29 June 2013

As an example, we consider the magnetic storm on 27-29 June, 2013 that was initiated by an interplanetary shock arrival at ~15:00 UT on 27 June. The IMF Bz fluctuated around 0, but after ~08:00 UT on 28 June, IMF Bz gradually turned southward (<0) and remained steady at about -10 nT until ~12:00 UT on 29 June. This produced driving of the magnetosphere into a magnetic storm, during which geomagnetic indices reached maximal values of |Dst| ~120 nT and AE~1000 nT.

This period coincided with a period of maximum of magnetic bay magnitude at the IMAGE magnetic stations (Fig. 1). The magnetic bay was observed only in the *X*-component. During the period of maximal magnetic disturbance, intense Pi3 pulsations were superposed on the magnetic bay. These pulsations are not quasi-sinusoidal waves like typical Pc5 pulsations; they are rather quasi-periodic sequences of magnetic impulses. The time scale of these oscillations varies from ~20 min at lower latitudes up to ~10 min at higher latitudes. During the maximal geomagnetic disturbance (at the minimum of the magnetic bay), a burst of magnetospheric energetic electron precipitation occurred, as evident from intense irregular variations of riometer absorption (up to ~50%) at SOD (Fig. 1).

During this substorm extremely high values of GIC were recorded (up to ~120 A per node) at station VKH, from ~01:00 to ~03:00 UT on 29 Jun. 2013 (Fig. 2).

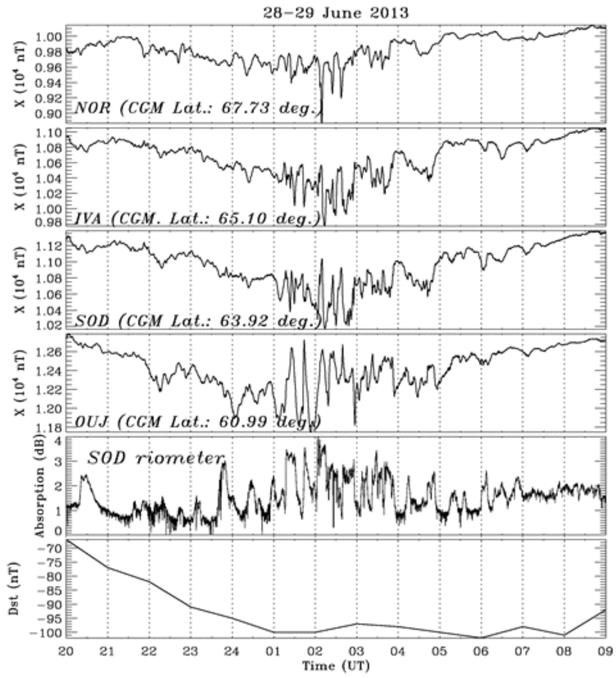

Figure 1. X-component of geomagnetic fields at the latitudinal array of stations NOR-IVA-SOD-OUJ between 20 UT on 28 Jun. 2013 and 09 UT on 29 Jun. 2013; riometer absorption at station SOD; Dst index. Geomagnetic latitudes are indicated near the station codes.

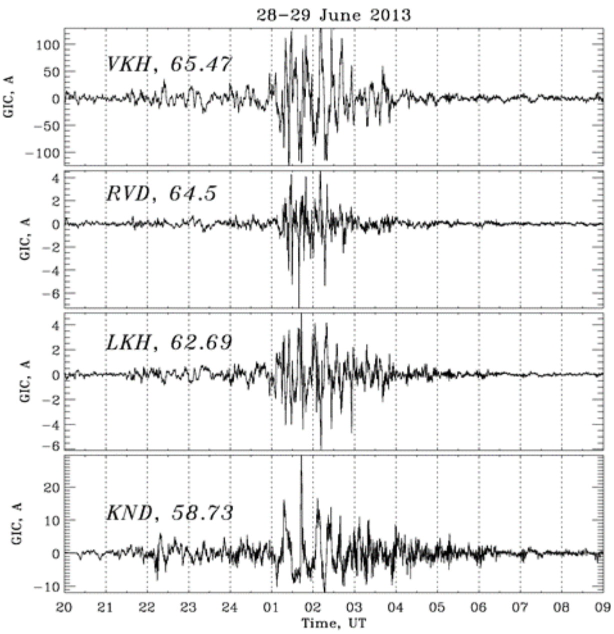

Figure 2. GIC data at stations VKH, RVD, LKH, and KND between 20 UT on 28 Jun. and 09 UT on 29 Jun. Geomagnetic coordinates are shown near station codes.

During the magnetic storm the magnetic disturbance gradually increased and then slowly decayed, and was mainly oriented in the X-direction. However, during the maximal disturbance magnetic variations became more chaotic. Comparison of the magnitude of magnetic disturbances ΔX and ΔY with amplitudes of time derivatives |d*X*/dt|, |d*Y*/dt| (Fig. 3) shows that though the magnetic disturbance was much larger in the X-component than in the Y-component, |Δ*X*|>>|Δ*Y*|, the time derivative |d*Y*/dt|≥600 nT/min was larger than the time derivative |d*X*/dt|≥500 nT/min. Therefore, variations of both horizontal components provided a similar contribution to the increase of |d**B**/dt|. Magnetic field variations are composed from time variations and variations caused by fast azimuthal drift of Pi3 structures. The vector diagrams of ionospheric current variations for the period between 12:00 UT on 28 June and 12:00 UT on 29 June (Fig. 4.) with time cadence 1 min show that the Pi3 pulsations were a sequence of localized vortex-like structures.

The method of 2D equivalent currents reveals the formation of the vortex-like intensifications during the growth of GIC with epicenter at 66°-67° geomagnetic latitudes, i.e. under the Kola Peninsula (Fig. 5).

According to the electromagnetic induction low the GIC should be proportional time derivate dB/dt of geomagnetic field variations. But in considered case the GIC intensity better correlate to the geomagnetic field variations B than with dB/dt (Fig. 6). It is seen from the visual inspection of the magnetograms. For the time interval 01.00-04.00 UT the correlation coefficient is following R (I_{GIC} - Hx)=0.7, R (I_{GIC} – Hy)=0.3, R (I_{GIC} – dHx/dt)=0.05, R (I_{GIC} – dHy/dt)=0.003. The spectrum analysis for the time interval 00.30-04.40 UT shows the presence of the common peak at 1.2 mHz (Fig. 7). The dHx/dt, dHy/dt shows presence a lot of other frequencies. So, we suppose that these extreme values are caused not only by the temporal variations of the B but also spatial variations of the vortex-like ionosphere current systems.

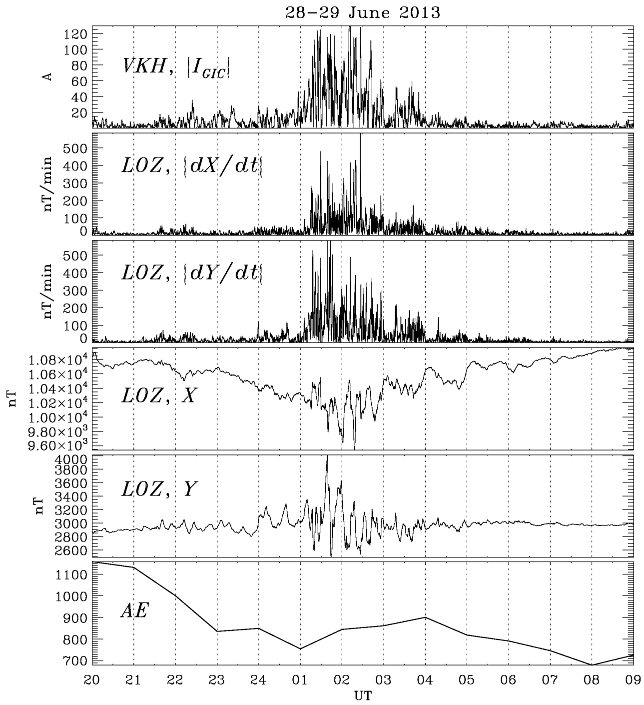

Figure 3. Comparison between GIC amplitudes, time derivatives |dX/dt| and |dY/dt| [nT/min], and ΔX and ΔY components of geomagnetic field [10^4·nT] at nearby stations VKH and LOZ between 20 UT on 28 Jun. 2013 and 09 UT on 29 Jun. 2013; hourly averaged AE index.

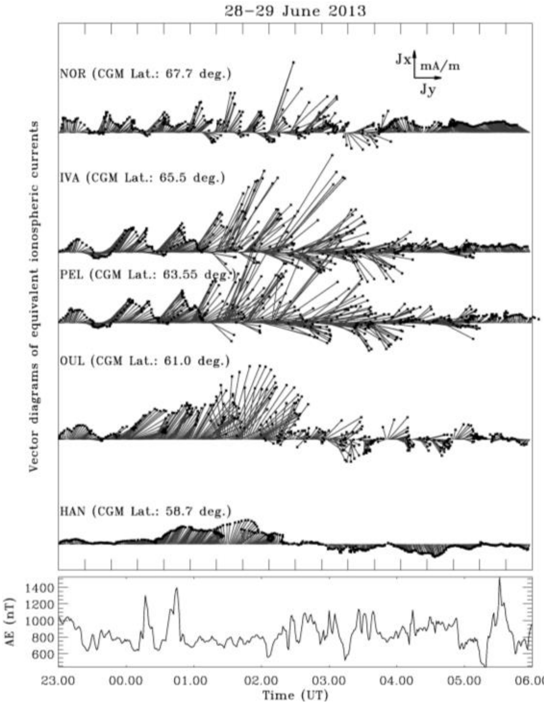

Figure 4. Vector diagrams of 1-min equivalent ionospheric currents corresponding to Pi3 pulsations for the period June 28, 12 UT - June 29, 12 UT with time cadence 1 min.

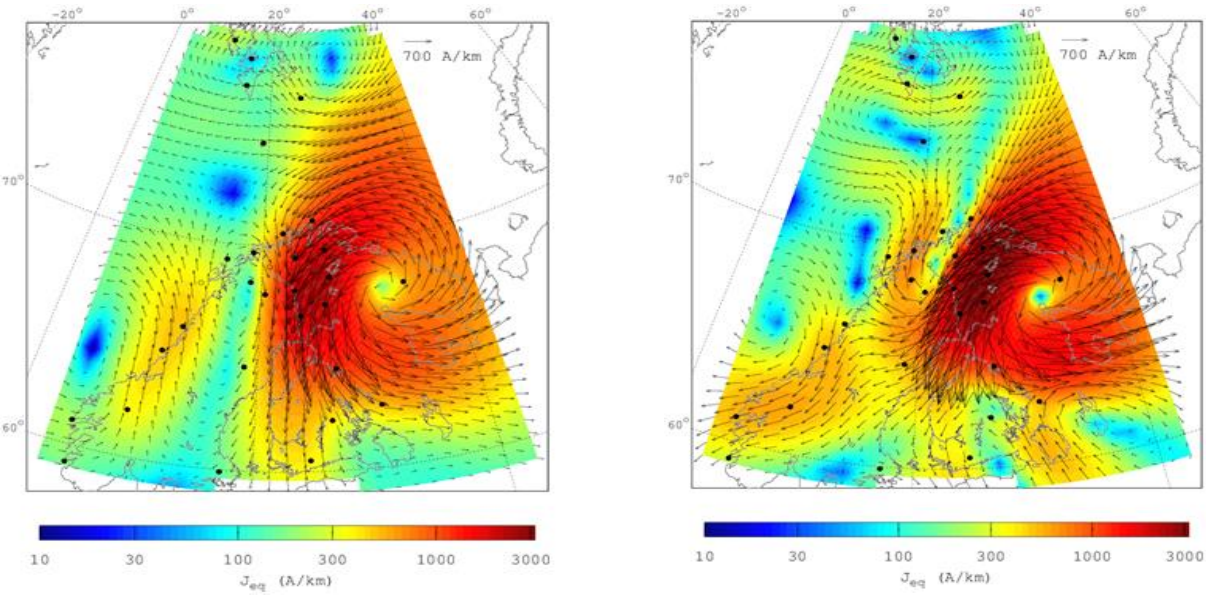

Figure 5. The 2D model of equivalent ionosphere currents constructed from the IMAGE magnetometer data for the 29 June 2013 at 01.25 UT (*left*) and 02.10 UT (*right*).

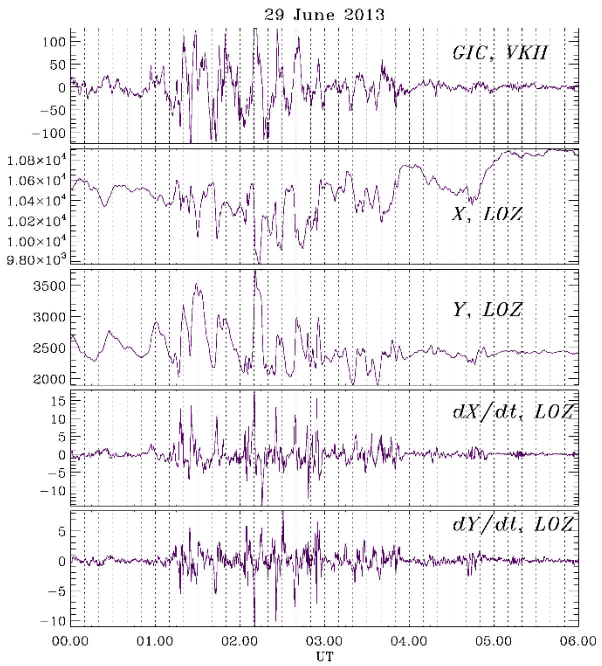

Figure 6. GIC at VKH station; variations of X, Y-component of the geomagnetic field at LOZ station; variations of derivates dX/dt, dY/dt at LOZ station.

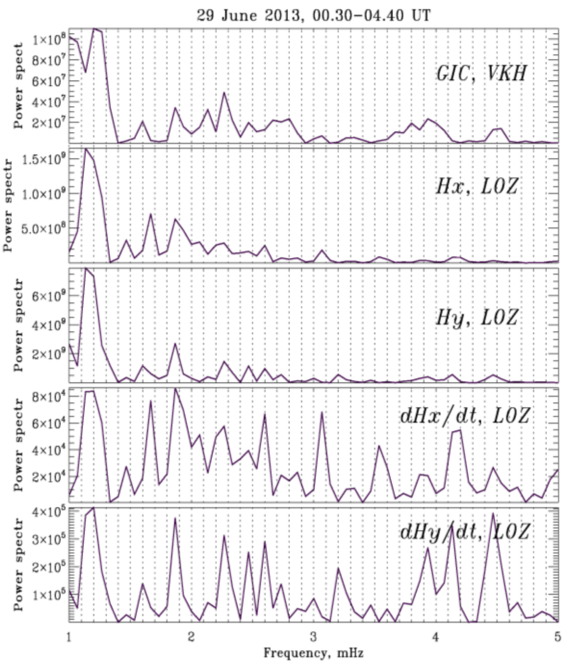

Figure 7. Spectrum of GIC variations at VKH station; spectrum of X, Y-component variations of the geomagnetic field at LOZ station; spectrum of dX/dt, dY/dt at LOZ station.

4. Conclusions

At auroral latitudes, the large-scale structure of the X-component of the disturbed geomagnetic field is mainly determined by the ionospheric East-West electrojet. In smaller regional scales, weaker but rapidly varying localized vortex-like current systems are superposed on the electrojet. These current structures produce intense GICs, as observed by the recording system of the power lines in the Kola Peninsula.

A quasi-periodic sequence of localized vortex-like structures observed by magnetometers as Pi3 pulsations produces very high values of GIC (up to ~120 A) for the 28-29 June 2013.The night-side solitary vortices observed as magnetic pulses with large amplitudes superposed on the substorm-related magnetic bay. These results have confirmed that GIC cannot be modeled by a simple model of the extended ionospheric current and dictate the necessity to take into account superposed localized vortex-like current systems. Large GIC values may be caused not only by the temporal variations of the B but also spatial variations of the vortex-like current systems.

Acknowledgements. This study is supported by the grant № 16-35-60049 mol_a_dk from the Russian Foundation for Basic Research. We thank the national institutes that support the IMAGE magnetic observatories (*http://www.ava.fmi.fi/image*). The interplanetary parameters were taken from the OMNI database (*https://omniweb.gsfc.nasa.gov*).

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