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GICS IN THE MAIN TRANSMISSION LINE "NORTHERN TRANSIT" IN RUSSIA AND IN THE MÄNTSÄLÄ FINLAND PIPELINE: A CASE STUDY

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Abstract. Geomagnetically induced currents (GICs), arising both on power lines and on pipelines, may have strong negative impact on the technological networks up to accidents ("blackouts"). Magnetospheric disturbances are one of the factors in the appearance of GICs, however there is no unambiguous relationship between substorm and presence of currents. In this paper, we consider two intense cases of GIC (15 March 2012 and 17 March 2013), registered on two different technological networks: 1) on the "Northern Transit" power line (Vykhodnoy, Revda and Kondopoga stations) located in the auroral zone, 2) on the Finnish natural gas pipeline near Mäntsälä located in the subauroral zone. Both GIC cases are compared with substorm development in the auroral zone, using data from IMAGE magnetometers network and MAIN camera system in Apatity. We found a good correlation between the GIC appearance and variations of geomagnetic indexes: IL – index, which characterized of westward electrojet intensity on the IMAGE meridian and Wp - index, which describes the wave activity of the substorm. Besides, it was shown also a good correlation between GICs and the thin spatio-temporal structure of the substorm development (the appearance and the propagation to the pole of substorm activations), which is appeared both in the magnetic data and in the all sky camera images.

Introduction

Space weather generally refers to the physical conditions in the Sun-Earth system that can affect the performance of ground-based technological systems. During geomagnetic disturbances (storms, substorms, supersubstorms, magnetic pulsations) very strong ionospheric currents can develop, which may lead to substantial interruptions in terrestrial electrical networks ([1], [2], [3], [4]). Rapid changes of the geomagnetic fields cause geoelectric fields which can produce intense, low-frequency, quasi-direct currents, co-called geomagnetically induced current (GIC) in the ground and electrical power systems [5]. The GIC intensity depends both on the intensity of magnetic disturbances during geomagnetic storms or substorms, and on the configuration of the system, ground conductivity, coastal effects, etc. [6].

It was shown that geomagnetic field disturbances associated with magnetic storms and substorms are known as the key factor for the generation of GICs. Recently by study of intense GICs (> 30 A) during 21 years (1999 through 2019) at the Mäntsälä, Finland (57.9° magnetic latitude) gas pipeline was shown that the most frequent (76%) cause of all of these GIC events are auroral electrojet intensifications during supersubstorm (SSS: $SML < -2500$ nT) and intense substorm (-2500 nT $< SML < -2000$ nT) [4]. Therefore, probably, strongest GIC events are recorded in the high geomagnetic latitude zone, where usually registered the large amplitudes of magnetic disturbances associated with the increasing and the motion of auroral electrojets.

On the other hand, an important part of the task of protecting against the negative effects of space weather is the monitoring of disturbances in the geomagnetic field and registration of the development of GICs in real power systems. So, within the framework of the EURISGIC scientific program, the system of continuous registration of the GIT was created at a number of transformer substations of the power line located on the Kola Peninsula [7]. It should be noted that system "Northern Transit" is located precisely in the auroral latitudes, where substorms are usually observed.

The purpose of our work is the study of the connection between the development of a supersubstorms [8] and intense substorms and the appearance of geomagnetically induced currents (GICs). For observations of GICs appearance on the different latitudes used data from the system "Northern Transit" and from the Mäntsälä, Finland gas pipeline. Using these systems, we could trace the GIC appearance from st. Mäntsälä, Finland to st. Vykhodnoy, Russia, from 57.9 to 64.9 degrees of geomagnetic latitude and could compare their appearance with the space-time development of the substorms, with substorm expansion to the pole.

We selected cases where the GICs on the st. Mäntsälä exceeded 30 A, and there were observations along the "Northern Transit" chain. In this article, we consider two events of intense GICs (March 15, 2012 and March 17, 2013) recorded in two different technological networks during the observation of the substorm on the Scandinavian meridian.

Data

Geomagnetically induced currents (GICs) were registered by two different technological networks:

- 1) on the "Northern Transit" power line located in the auroral zone, on Vykhodnoy (68.8°N and 33.1°E geographic), Revda (67.9°N and 34.1°E geographic) and Kondopoga (62.2°N and 34.3°E geographic) stations.
- 2) on the Finnish natural gas pipeline near Mäntsälä, located in the subauroral zone (57.9°N geomagnetic).

Fig. 1 shows location of the points of registration of the GIC and the location of magnetometers.



Figure 1. The layout of the measuring devices: red circles - the registration of the GIC, blue circles - the location of magnetometers.

Substorm development was determined both by magnetograms from global networks: IMAGE magnetometers network <http://space.fmi.fi/image/> and the SuperMAG network <http://supermag.jhuapl.edu/> [8] and by geomagnetic IL- and Wp-indexes. The Wp (wave and planetary) index is related to the power of the Pi2 pulsation wave at low latitudes [9], and the IL index shows the variation of the magnetic field at the selected IMAGE stations, that is, in essence, it is similar to the AL index, which is associated with the auroral electrojet [10]. The global spatial distribution of electrojets was determined from the maps of magnetic field vectors obtained on the SuperMAG network. The active auroras were observed by Multiscale Aurora Imaging Network (MAIN), by all-sky camera located in Apatity (<http://aurora.pgia.ru>). The solar wind and IMF parameters are taken from 1-minute OMNI data (<https://cdaweb.sci.gsfc.nasa.gov/>) and the catalog of large-scale solar wind phenomena (<ftp://ftp.iki.rssi.ru/omni/>).

Results

1. First event on 15 March 2012

In the period on 7-17 March 2012, solar wind and interplanetary magnetic field (IMF) conditions were very complicated, it is one of the most disturbed periods during the ascending phase of Solar Cycle 24. Four consecutive magnetic storms were developed, occurred on 7, 9, 12, and 15 March, respectively [11]. Very intense GIC (~30 A) was recorded on Mäntsälä station at ~17 UT during the fourth storm (S4) (SYM/H = -80 nT) and may be associated with a solar wind spike of density [4]. In Figure 2a shown the GIC registrations on st. Mäntsälä and on Northern Transit station (Vykhidnoy, Revda, Kondopoga) from 14 to 18 UT on 15 March 2012. It is seen, that small GICs were registered at ~15 UT on both networks, then at ~17 UT were observed very intense GIC on st. Mäntsälä (~39 A) and intense GIC at st. Vykhidnoy (~18A), at that moment GIC were also registered at st. Revda (~2A) and st. Kondopoga (~7A). According to IMAGE magnetometers data, the substorm occurred at ~17 UT on Nurmijarvi (NUR) and propagated to the NyAlesund (NAL) (Fig. 2b). At the same time substorm development from subauroral to high latitudes has a good agreement with appearance of GICs both on Northern Transit stations and on st. Mäntsälä station. It is seen also that these GICs also have a good correlation with two geomagnetic indexes: Wp and IL (top panels of Fig. 2a). Three maps of SuperMAG magnetometer vectors (Fig. 2c) demonstrated that it was isolated substorm and disturbances occurred precisely over Kola Peninsula, where all our GICs detectors are located. Note, at the Fig.2b are schematically marked the two time moments of solar wind shock wave and spike of density. At the moment of the shock wave arrival, the disturbances were observed only at high latitudes stations and the GICs were not intense (>10 A). While the intense substorm and GICs developed after the density jump in the solar wind.

2. Second event on 17 March 2013

On 17.03.2013 a CME passed by the Earth, which included two intervals of the negative B_z IMF observed during SHEATH and during the magnetic cloud (MC), and a two-stage magnetic storm with $Dst \sim -140$ nT was developed. GICs registrations on st. Mäntsälä and on Northern Transit stations from 15 to 21 UT on 15 March 2012 are presented in Fig.3a. The shock wave coming led to the development of a small substorm at high latitudes $\sim 15:50$ UT (Fig 3b), which manifested itself in the appearance of intense GIT on Vykhodnoy (~ 27 A) and small GITs on Revda (~ 3 A), Kondopoga (~ 4 A), on Mäntsälä (~ 12 A) stations.

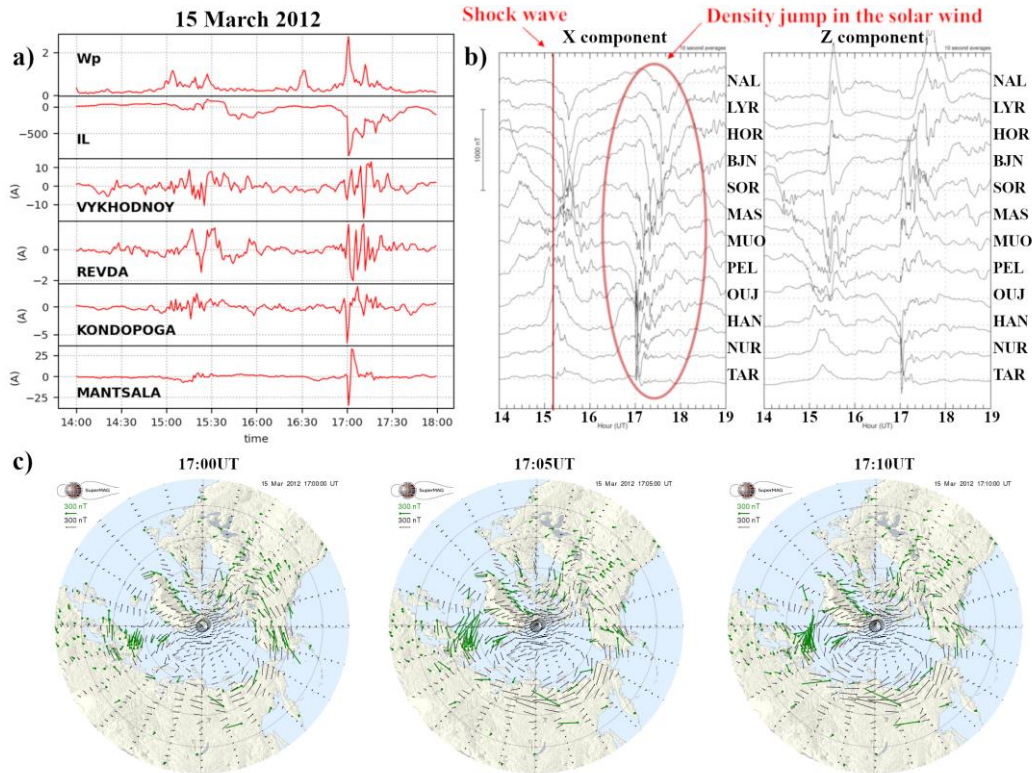


Figure 2. First event on March 15, 2012: GIC registration on Mäntsälä station and on Northern Transit stations (a); X- and Z- components of geomagnetic field from IMAGE magnetometers (chain TAR-NAL), red oval shows the substorm for the study (b); three maps of magnetic vectors from SuperMAG network (c).

As seen from Fig.3b, at ~ 18 UT, the second more intense substorm began, which consisted from three intensifications (18:00 UT, 18:20 UT, 18:40 UT) - three negative bays at the low-latitudinal IMAGE stations and, as a result, the GICs appeared at the on Mäntsälä (~ 32 A), Kondopoga (~ 11 A) and Revda (~ 2 A) stations. The second and third intensifications are detected on keogram from all-sky-camera in Apatity (red vertical lines) (Fig. 3.c) as well as on magnetic vector maps SuperMAG (Fig. 3.d).

On Vykhodnoy GIC data, we see the spike (~ 27 A) at ~ 19.30 UT that a little bit later than second substorm happen, this spike occurs due to the third substorm. Third substorm are marked by third red oval on magnetometers data from IMAGE stations (Fig 3b). This substorm disturbance propagated from OUL to SOR stations, where station Vykhodnoy located.

It is seen a good correlation between GICs appearance and behavior of IL- and W_p - indexes (Fig 3a). But it should be noted, that in the W_p index profile seen only two substorms, it's related to the nature of this index – it's calculated on low latitudinal and equatorial magnetometer stations, when IL index calculated on high latitudinal magnetometer stations so all three substorm seen in its profile.

Conclusions

- 1) It is shown a good correlation between the GIC appearance and increasing of geomagnetic indexes: IL – index (westward electrojet intensity on the IMAGE meridian) and W_p – index (the wave activity of the substorm).
- 2) It was possible to trace the development of GICs on the meridional profile (from Mäntsälä to Vykhodnoy) in accordance with the thin spatial - temporal structure of the substorm (the appearance and the propagation to the pole of three substorm activations).

Aknowlegments

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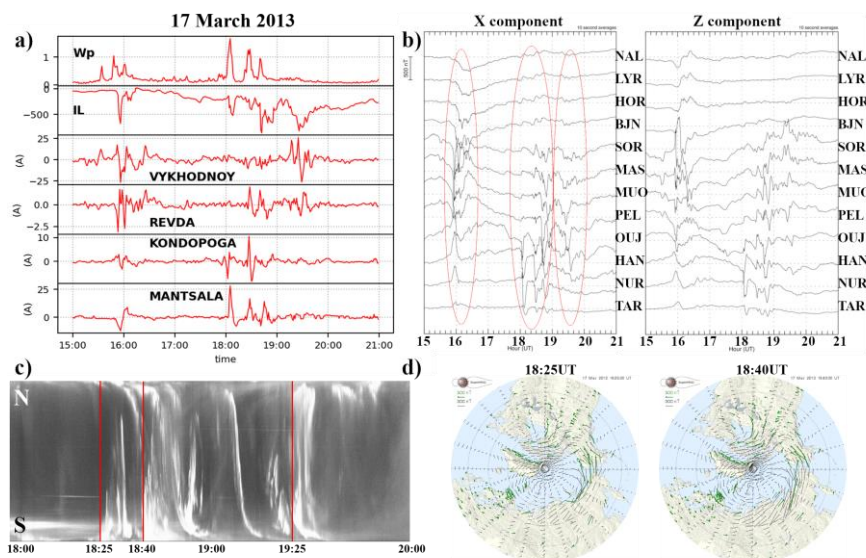


Figure 3. Second event on March 17, 2013: GIC registration on Mäntsälä station and on Northern Transit stations (a); X- and Z- components of geomagnetic field from IMAGE magnetometers (chain TAR-NAL), red oval shows the substorms for the study (b); the keogram of all-sky camera in Apatity from 18 to 20 UT (c); maps of magnetic vectors from SuperMag network (d).

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