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Magnetic and electric field variations during geomagnetically active days over Turkey

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Abstract

Currents in the magnetosphere flow into the ionosphere during geomagnetic disturbances and are detected at the ground magnetic stations as Geomagnetically Induced Currents (GICs). In this paper, magnetic and electric field characteristics of the GICs at midlatitudes were studied using electric field and magnetic field observations in Turkey during the geomagnetically active intervals. A magnetotelluric station consisting of an electrometer and a magnetometer were set up in Bozcaada, Çanakkale (37.5°N, 106°E). Several cases that showed large electric and magnetic field fluctuations during geomagnetic disturbances were selected and the effects of geomagnetic activity were studied using the time derivatives of horizontal component of the magnetic field and the deviations in the magnetic and electric field components from the quiet background. In magnetic field data, quiet day Sq variations were removed using cubic spline fits. Similarly, the magnitude of the deviations in the electric field were determined by subtracting the background electric field determined by using cubic spline. Corresponding to the strong geomagnetic activity identified using Kp and Dst indices, high frequency, strong fluctuations in the magnetic field, its derivatives, and electric field were observed. These fluctuations in horizontal magnetic and electric field were compared with those seen during a magnetically quiet day. The close association between the fluctuations of the time derivatives of the horizontal magnetic field and electric field components were demonstrated. Two types of variations in the electric and magnetic fields corresponding to the different phases of the geomagnetic activity were identified: those corresponding to the initial phase including the sudden commencement and those to the main phase of the geomagnetic storm. The fluctuations in both magnetic field and electric field corresponding to the sudden commencement and the initial phase indicate the effects of magnetopause currents driven by the large solar wind dynamic pressure as associated with the coronal mass ejection (CME) events. Each event shows increased levels of ground level magnetic and electric field fluctuations corresponding to the CME compression at the subsolar magnetopause. High frequency, large fluctuations continue subsequently during the main phase in the presence of the geomagnetic storms. The fluctuations during the main phase were found to be different than those corresponding to the sudden commencements. GIC occurrences in our latitudes were shown to be associated with the sudden commencement and main phase of the geomagnetic storm activity. The time rate of change in horizontal component of the magnetic field showed perturbations on the order of 0.5 nT/s in our region. The sources of the GICs based on these observations were discussed. This study presents our preliminary results on the characteristics of the GICs over Turkey based on the simultaneous measurements of electric and magnetic field during the geomagnetic storms. It is the first study of the GICs in Eurasia region and the results contribute to the worldwide understanding and modelling efforts on the GICs.

Keywords: Geomagnetically Induced Currents (GICs); Electric and geomagnetic field; Sudden commencement; Geomagnetic storm; CME; Midlatitudes

1. Introduction

Understanding the space weather is essential for our space-born and ground based technological systems as well

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as astronauts in orbit and air crews on polar flights. One of the most direct and observable consequences of space weather on the ground is the enhanced currents which are known to be GICs. These currents flow through Earth-grounded systems and units that are composed of electrically conducting components, modulate the electrical currents on our power systems, result in failures in city power grids, telecommunication systems, and lead to corrosions in railways and pipelines that are used for the transport of oil in long distances.

A latest Space Weather issue (24 March 2016) compiles all the studies of GICs up to date published in different journals. It gives an exclusive collection of GIC studies including the sources, latitude variations, storm-substorm relations, modelling, hazards on ground systems, and measurement systems. In this study, we present the measurements of GICs at our latitudes, 37.5°N MLAT (Magnetic LATitude), bring out their characteristics and discuss the possible causes for their occurrences. GICs and their effects at different latitudes were studied widely and established well (Araki, 1994; Araki et al., 2006; Curto et al., 2007; Rastogi et al., 1997; Tsunomura, 1998; Trivedi et al., 2007; Wik et al., 2008; Liu et al., 2014; Watari et al., 2009; Marshall et al., 2012; Torta et al., 2012, 2014; Barbosa et al., n.d.; Matandirotya et al., 2015). Most of these studies used power grids to investigate GICs extensively, e.g. Wei et al. (2013) in North America, Boteler et al. (1998) in Canada, Viljanen and Pirjola (1994) in Finland, and Beamish et al. (2002) in UK-Scotland, Zhang et al. (2015) in China, Béland and Small (2004) in New Zealand, Pulkkinen et al. (2005) in Sweden. Depending on the latitude and strength of the magnetospheric activity, GIC magnitudes were found to vary from 10 s of Amperes (A) to several hundreds of Amperes. Kappenman (2003) reported GICs on the order of 200 A in high latitude regions of US. Watari et al. (2009) estimated GICs in central Japan on the order of 45 A during 13 July 1982 storm that caused 796 nT change in the horizontal component of the magnetic field. Trivedi et al. (2007) found GIC amplitudes of about 15 A in Brazil.

Mid- and low latitude GICs show similar signatures in general. Low latitude GICs or GICs at equatorial latitudes are dominated by the effects of the equatorial electrojet and superimposed on them are the effects from the magnetopause currents (Zhang et al., 2015). The main source of the large GICs occurring at the midlatitudes were found to be associated with the storm sudden commencement (SSC) or sudden impulse (SI) resulting from shocks in the solar wind (Marshall et al., 2012; Béland and Small, 2004; Huttunen et al., 2008; Fiori et al., 2014). CMEs or CIRs (Corotating Interaction Regions) cause GICs as a result of the increased dynamic pressure at the subsolar magnetopause (Huttunen et al., 2008; Fiori et al., 2014). Increased dynamic pressure creates magnetopause currents and gives rise to sharp increases in the magnetic field components measured on the ground. The sharp positive rise seen in Dst in response to the increase in magnetopause currents was named as Sudden Impulse (SI) and if this increase was followed by a main phase of the geomagnetic storm, then it was called storm sudden commencement (SSC). The effects of SSC and SIs in producing GICs were examined together in Fiori et al. (2014) under a generalized term "sudden commencement (SC)" to cover the effects of either SSC or SI. The similar terminology was also suggested by Joselyn and Tsurutani (1990) if the follow up main phase of the geomagnetic storm starts within the 24 h after the sudden impulse was seen. While at lower and midlatitudes the driver of the GICs are mainly the increase in the magnetopause currents (Zhang et al., 2015; Fiori et al., 2014), at high latitudes, auroral currents (e.g. Viljanen, 1997; Viljanen and Tanskanen, 2011; Fiori et al., 2014) and at equatorial and low-to-midlatitudes, equatorial electrojet contribute further on the effects of magnetopause currents (Carter et al., 2015; Zhang et al., 2015). Largest GICs at low and midlatitudes occurred during the main phase of the geomagnetic storms as associated with the intensification of the ring current (Zhang et al., 2015; Kappenman, 2006; Liu et al., 2009). However, GICs that occurred in response to SSCs were found to be stronger than those produced during the storm main phase (Zhang et al., 2015). The solar wind causes of GICs were studied in detail by Huttunen et al. (2008). They showed that the sheath and boundary layer regions of Interplanetary Coronal Mass Ejections (ICME) gave rise to stronger GIC variations than that of the ejecta. Fiori et al. (2014) grouped and compared the variations in the horizontal component of the magnetic field whether resulting from CME or High Speed Streams (HSS). They demonstrated that the CMEs were the main driving source for the strong high latitude enhancements of the horizontal component of the magnetic field while weak or absence of high latitude enhancements in the horizontal component of the magnetic field are caused by both CMEs and HSS. These suggest that the shock in the solar wind velocity is a strong contributing factor to the stimulation of the strong ionospheric plasma convection flows within the auroral oval that give rise to geomagnetic disturbances on the ground levels (McPherron, 1991).

Viljanen et al. (2001) studied GICs by analyzing the variations in the time derivative of the horizontal magnetic field from 1982 to 2001 and showed that the strong GICs were associated with deviations larger than 1 nT/s in the time derivative of the horizontal magnetic field. The sudden increases in the time derivative of the magnetic field ($\mathrm{d}B/\mathrm{d}t$) in response to SCs were observed independent of the occurrence of the geomagnetic storm (Fiori et al., 2014; Zhang et al., 2015). In their study, any change in $\mathrm{d}B/\mathrm{d}t$ larger than 1.67 nT/s induced GIC currents, however, variations above 3.33 nT/s resulted in strong GIC events, especially at high latitudes. This was attributed to the effects of the ionospheric plasma convection superimposed on the sudden commencement effects at the high latitudes (Fiori et al., 2014). As a continuation of their work, Viljanen et al. (2006) studied GICs larger than 1 nT/s for

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