The statistical analysis of the Geomagnetically Induced Current events occurred in Guangdong, China during the declining phase of solar cycle 23 (2003–2006)

Y Y Ni

1 School of Mathematics and Physics, North China Electric Power University, 2 Beinong Road, Changping District, Beijing 102206, China

Email: niyiyi058@163.com

Abstract. We study the interplanetary causes of intense geomagnetic storms (Dst ≤ -100 nT) and the corresponding Geomagnetically Induced Current (GIC) events occurred in Ling’ao nuclear power station, Guangdong during the declining phase of solar cycle 23 (2003–2006). The result shows that sMC (a magnetic cloud with a shock), SH (sheath) and SH+MC (a sheath followed by a magnetic cloud) are the three most common interplanetary structures responsible for the storms which will cause GIC events in this period. As an interplanetary structure, CIR (corotating interaction regions) also plays an important role, however, the CIR-driven storms have a relatively minor effect to the GIC. Among the interplanetary parameters, the solar wind velocity and the southward component of the IMF (interplanetary magnetic field) are more important than solar wind density and the temperature to a geomagnetic storm and GIC.

1. Introduction

The solar plasma emitted by the Sun interact with the Earth’s magnetic field, affecting the physical processes in the magnetosphere and ionosphere. Their net result is recorded at the Earth’s surface as variations of geomagnetic and geoelectric fields. The electric fields induced at the Earth’s surface will drive geomagnetically induced currents (GIC) in the circuit of power transmission lines and neutral-grounded transformers[1]. Intense variations of the geomagnetic field caused by solar activity are called geomagnetic storms, which means GIC is one of the manifestations of geomagnetic storms. Previous studies have found that GIC poses a potential threat to the technological systems such as power lines, pipelines and railway systems with severely distorting exciting currents, which will damage the transformers and even threat the safe operation of the whole power system[2].

The GIC events are used to be thought that only occurred in high latitudes areas such as North America and northern Europe. For example, the most well-known GIC events are the province wide blackout in Quebec, Canada, in March 1989 and the blackout in Malmö, a city of southern Sweden, during the Halloween storm of October 2003[3]. But with the study proceeding, people have found that the mid and low latitudes regions also can be influenced by GIC. In China, it has been found several times of GIC events in Guangdong and Jiangsu Province. Although GIC has not caused severe damage, it is still significant and urgent to estimate the GIC levels in Chinese power grids and to determine the effects of GIC on Chinese present and planned power systems.

When investigating the drivers of space weather at Earth, in particular the GIC, it is important to distinguish between the different interplanetary structures, which have been previously reported to produce significantly varying responses in the Earth magnetosphere and it is therefore reasonable to...
expect different responses for GICs[4]. Gonzalez have found that the most common interplanetary structures leading to the development of an intense geomagnetic storm (Dst ≤ -100 nT) are magnetic cloud (MC), sheath field (SH), sheath fields followed by a magnetic cloud (SH+MC) and corotating interaction regions (CIR)[5]. However, the relative importance of each driving structures has been found to vary with the solar cycle phase.

The solar cycle 23 (1996–2006) can be divided into three phases: the rising phase (1996–1998), the maximum phase (1999–2002) and the declining phase (2003–2006). In this paper, the cases we chosen are all in the declining phase of solar cycle 23. The Dst index is a measure of the strength of the ring current and widely used for measuring the intensity of geomagnetic storms. According to the peak Dst index, the storms can be divided into three types: intense storms (Dst ≤ -100 nT), moderate storms (-100 nT < Dst ≤ -50 nT) and small storms (Dst > -50 nT). The intense storms usually happen in the maximum and declining phases of the solar cycle.

The purpose of this paper is to study the intense geomagnetic storms (Dst ≤-100 nT) occurred in the declining phase of solar cycle 23 (2003–2006) and the GIC events caused by these storms. We will study the interplanetary sources of the storms, finding what kind of interplanetary structures may cause GIC events and the difference between the storms driven by different interplanetary structures. We use the solar wind and interplanetary magnetic field (IMF) data observed by the ACE (Advanced Composition Explorer) satellite, combining with the Dst data, to analyze the influence of each interplanetary parameter to the geomagnetic storms and GICs. The GIC data we used is from Ling’ao nuclear power station (N22E114) in Guangdong Province, so we choose the Dst data of Zhaoqing geomagnetic station (N23E112).

2. Statistical analysis

Echer et al. have identified 90 intense geomagnetic storms (Dst ≤-100 nT) during solar cycle 23[6] and we choose 29 of them listed in table 1 which occurred during 2003–2006. The columns in the table are the date of peak Dst, the value of peak Dst, the interplanetary structure identified as the cause of the storm main phase and the peak value of the GIC intensity if it has.

| Date       | Dst (nT) | IP Structure | IGIC (A) | Date       | Dst (nT) | IP Structure | IGIC (A) |
|------------|----------|--------------|----------|------------|----------|--------------|----------|
| 2003/05/29 | -144     | SH           | 11.89    | 2004/11/10 | -289     | SH+MC        | 42.82    |
| 2003/06/18 | -141     | SH           |          | 2004/11/12 | -109     | SH           |          |
| 2003/07/12 | -105     | CIR          |          | 2005/01/18 | -121     | CIR          | 6.98     |
| 2003/08/18 | -148     | sMC          |          | 2005/05/08 | -127     | CIR          |          |
| 2003/10/29 | -353     | SH+MC        | 57.05    | 2005/05/15 | -263     | sMC          |          |
| 2003/10/30 | -383     | SH           | 48.57    | 2005/05/30 | -138     | nonMC        |          |
| 2003/11/20 | -422     | sMC          | 23.86    | 2005/06/13 | -109     | CIR          |          |
| 2004/01/22 | -149     | nonMC        | 5.71     | 2005/06/24 | -216     | sMC          | 42.82    |
| 2004/04/04 | -112     | SH           |          | 2005/08/24 | -216     | sMC          | 42.82    |
| 2004/07/25 | -148     | sMC          |          | 2005/09/11 | -123     | SH           |          |
| 2004/07/27 | -197     | SH+MC        | 18.26    | 2006/04/14 | -111     | sMC          |          |
| 2004/08/30 | -126     | sMC          |          | 2006/12/15 | -147     | sMC          | 42.82    |
| 2004/11/08 | -373     | sMC          | 5.36     |            |          |              |          |

* The date of GIC events recorded by Ling’ao nuclear power station, Guangdong.

The interplanetary remnants of coronal mass ejections (CME) are called as ICME. MC (magnetic cloud) is a subset of the ICME. When the B_y or B_z component of IMF display a 180° rotation, we can consider an ICME to be a MC. If the MC is preceded by an interplanetary fast shock but only the MC field causes the storm, we call this type of structure as a MC with a shock (sMC). Otherwise, we call it...
as a MC with no shock (nsMC). NonMC means any ICME that does not follow the MC criteria. SH (sheath field) is the fields present in the region between the interplanetary shock and the driver ICME. SH+MC stands for a sheath followed by a magnetic cloud. CIR (corotating interaction regions) corresponds to the interaction regions between high and low speed solar wind streams[6].

One can see in table 1 that the three most common interplanetary structures of intense storms during 2003-2006 are sMC, SH and CIR. These three types of structures account for 76% of the whole interplanetary structures causing intense storms during the declining phase of solar cycle 23, with CIRs causing 17%, sMCs 35% and SHs 24% of the storms. The sMC, SH+MC and SH are the three most dominant interplanetary structures responsible for the GIC events, with a number of 4, 3 and 3 cases respectively. The sMC, SH+MC, SH, nsMC and nonMC all can be classified as ICME[7]. We can compute that the GIC events caused by ICMEs account for 85% with 11 cases and CIRs account for 15% with 2 cases. Borovsky and Denton have found that the biggest GIC events are from CME drivers, whereas CIR-driven storms had a relatively minor effect[8]. As the table 1 shown, among the 13 events there are only three cases that the strength of GIC less then 10A, and two of them are driven by CIR. This result tallies with Borovsky’s conclusion.

3. Analysis of typical cases
For the purpose to find the differences between the storms driven by different interplanetary sources, we choose two cases driven by CIR and sMC, respectively.

![Figure 1](image)

**Figure 1.** The geomagnetic storm and the GIC event occurred from 14 to 16 December 2006.
Figure 1 shows a sMC-driven storm during 14–16 December 2006. The parameter V stands for the solar wind velocity, N for the number density of solar wind plasma, $T_p$ for the proton temperature, B for the strength of IMF and $B_z$ for the north-south component of IMF. $B_s$ is the southward component
of IMF ($B_s = -B_z$ for southward field, $B_s = 0$ for northward). As the China National Space Weather Center reported, a X 3.4 solar flare erupted at 10:40 UT 13 December 2006, accompanied by a CME. The CME arrived at the earth and caused the intense geomagnetic storm in the early morning of day 15. We can see an interplanetary shock occurred at ~16:00 on day 14 December, then the parameter $N$, $T_p$, $V$ and $B$ all start to increase quickly. The component of the IMF $B_z$ began to fluctuate in the north-south direction and declined suddenly at ~00:00 on day 15. In the main phase of the storm, the $N$ and $T_p$ were back to the normal value basically, while the speed of the solar wind and the strength of IMF began to decline from the peak value. The component $B_z$ had a long time continuous southward turning and reached a minimum value at ~08:00 on day 15. The peak of the storm occurred at ~08:00 UT on 15 December, with a peak $Dst$ of -433 nT and a peak GIC of 14.52A.

Figure 2 shows an example of a CIR-driven geomagnetic storm caused by the southward components of oscillating $B_z$ fields within the CIR between 31 August and 1 September 2005. The high speed stream (HSS) and low speed stream (LSS), as well the region of compressed magnetic field and plasma, are indicated in the figure. The storm peak occurred at ~15:30 UT on 31 August, with a peak $Dst$ of -378 nT. The GIC event caused by this storm occurred from 14:30 UT 31 August to 02:30 UT 2 September. The peak value of this GIC is 5.34A. According to statistics, the CME-driven storms have a greater value of $B_s$, a higher speed of the solar wind and a smaller peak $Dst$, while the CIR-driven storms have a bigger numerical interval of solar wind proton density[9].

![Figure 2](image_url)

**Figure 2.** The geomagnetic storm and the GIC event occurred from 31 August to 1 September 2005.

4. Discussion and Conclusion
For the declining phase of solar cycle 23, the three most common interplanetary structures driving intense storms are sMCs (35%), SHs (24%) and CIRs (17%). These three driving structures are
responsible for almost 76% of intense storms. However, the geo-effective of CIRs is less, leading to the storms with peak Dst values only between -100 nT and -150 nT. The sMC, SH+MC and SH are the three dominant structures responsible for the GIC events, with a percentage of 31%, 23% and 23% respectively. Considering sMC, SH+MC, SH, nsMC and nonMC as ICMEs, about 85% of GIC events are caused by ICMEs and 15% by CIRs.

From the typical cases, we can see that the storms caused by different interplanetary structures have different change process. The ICME-driven storms are well matched with the corresponding GIC events with bigger peak values, whereas CIR-driven storms are not matched so well. During a ICME-driven geomagnetic storm such as case 1, the Dst often rises in a short duration because of the arrival of the CME shock. The decrease of the Dst during the main phase is closely related to the southward component of the IMF. Comparing with other structures, the CIR-driven storms have a relatively minor effect to the GIC. In the two cases caused by CIRs, the strength of GIC are both less than 10A.

Among the interplanetary parameters, the solar wind velocity $V$, the southward component of the IMF $B_s$ and the duration time $T$, are the most dominant factors to geomagnetic storms. According to statistics, when $B_s > 10$ nT and $T \geq 3h$, it is more likely to cause an intense storm[10]. The roles of the solar wind density $N$ and the temperature $T_p$ in space weather studies are complex. At present, the study shows that they have a weak correlation with geomagnetic indices such as Dst index. We will delve more deeply into the problem to find a possible linear relation between the interplanetary parameters and the GIC values for the prediction of the potential GIC events in the future.

References
[1] Liu C M, Liu L G, Pirjola R and Wang Z Z 2009 Space Weather 7 S04005
[2] Boteler D H, Pirjola R J and Nevanlinna H 1998 Adv. Space Res. 22 17–27
[3] Viljanen A 2011 Space Weather 9 S07007
[4] Savani N P, Vourlidas A, Pulkkinen A, Nieves-Chinchilla T, Lavraud B and Owens M J 2013 Space Weather 11 245–61
[5] Gonzalez W D, Echer E, Gonzalez A L and Tsurutani B T 2007 Geophys. Res. Lett. 34 L06101
[6] Echer E, Gonzalez W D, Tsurutani B T and Gonzalez A L 2008 J. Geophys. Res. 113 A05221
[7] Chen C, Zhao Z W, Sun S J, Ban P P and Wang B J 2016 Chinese Journal of Radio Science 31 670–5
[8] Borovsky J E and Denton M H 2006 J. Geophys. Res. 111 A07S08
[9] Shen X F, Ni B B, Gu X D, Zhou C, Liu Y, Xiang Z and Zhao Z Y 2015 Chinese Journal of Geophysics 58 362–70
[10] Tong Y N, Liu S Q and Gong J C 2008 Chinese Journal of Space Science 28 513–21

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