GIC MEASUREMNTS IN JAPAN

Shinichi Watari
National Institute of Information and Communications Technology (NICT) Japan[1]

Keywords

Geomagnetically induced currents (GIC), Geomagnetic Storm, Space Weather (SWx)

Abstract
It is known that geomagnetically induced currents (GIC) influence electric power grids. In fact several serious electric power black-outs as GIC effects were reported to occur in the past. Although it is believed that power grid problems from GICs hardly occur in Japan because of the country's location at geomagnetically lower latitudes. However, it is important to estimate effects of GIC through measurement in preparing for the extreme events. Measurement of GICs was conducted at Memanbetsu, Hokkaido between December 2005 and March 2008 according to the close collaboration among National Institute of Information and Communications Technology (NICT), Hokkaido Electric Power Co., and Solar-Terrestrial Environment Laboratory (STEL), Nagoya University. In this measurement, GICs were measured associated with geomagnetic variations such as substorm-related disturbances. The measurement shows temporal variations of GICs have high correlation with geomagnetic field variations, rather than time derivatives of the geomagnetic field. This result suggests importance of underground conductivity on GIC. In this paper, we report our study based on this measurement.

Introduction

Space weather affects manmade systems, such as artificial satellites, electric power grids, navigation satellite systems (GNSS), high frequency (HF) radio communication, and so on [1, 2, 3, 4]. It is important for power companies to estimate a risk of effect by geomagnetically induced currents (GICs) [5, 6, 7, 8, 9, 10]. In Canada, electric power blackout of the Hydro-Quebec system occurred on March 13, 1989 associated with a large geomagnetic storm [2, 11, 12]. Most recent electric power blackout caused by GIC occurred on 30 October 2003 in southern Sweden, during a space storm called the Halloween storm [13, 14].

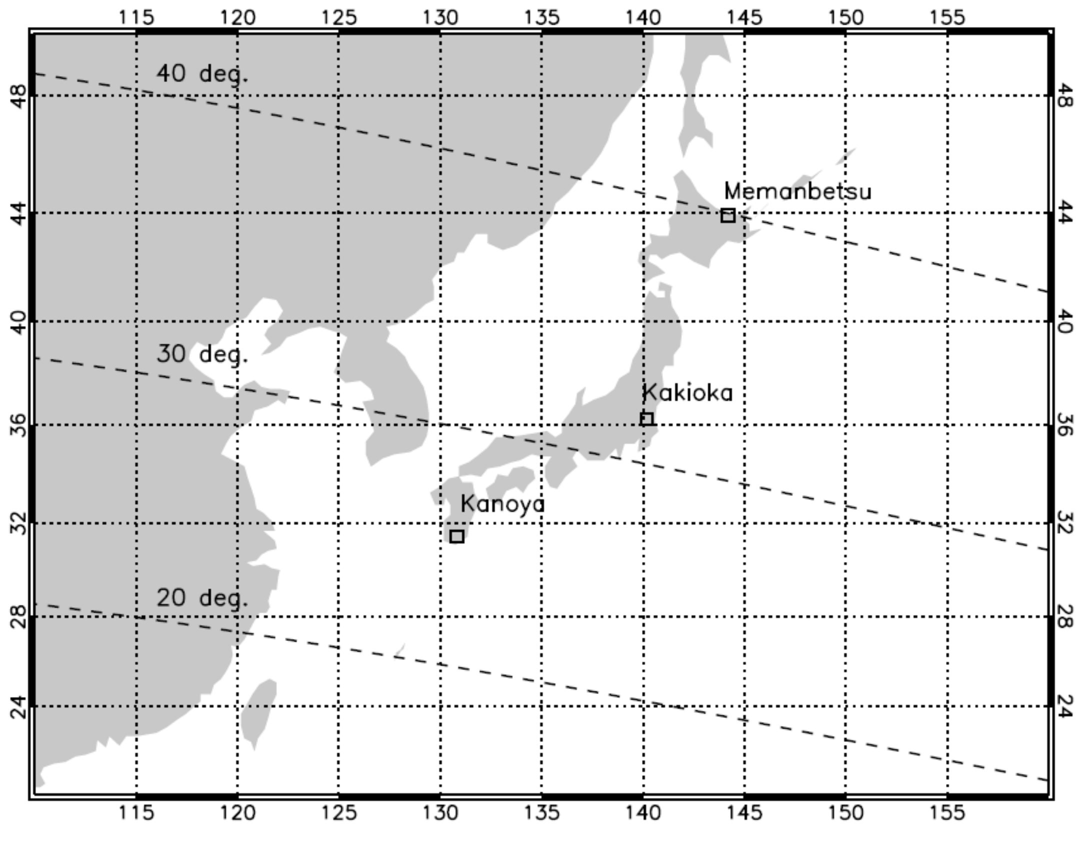
GIC effects on electric power grids have been noted since the 1940's. After the electric power blackout in Canada, DC excitation of transformers due to GIC was extensively studied [15]. For example, Tokyo Electric Power Co. in Japan made experiments this problem using scale models with linear dimensions 1/3 to 1/2 of those of actual power transformers [7]. Three models with different core structures were tested. The result showed susceptibility to DC excitation decreased in order of single-phase three-legged, three-phase five-legged, and three-phase three-legged. Temperature rise due to leakage flux are reduced to approximately one tenth changing core support material from magnetic to nonmagnetic material. The maximum temperature rise of approximately 110°C was measured in case of core plate and core support made by magnetic steel for a considerably high GIC level (approximately 200 A/3-phases). They concluded that temperature rises by GIC would not appreciable affect the lifetime of

[1] 4-2-1 Nukuikita, Koganei, Tokyo, 184-8795 Japan

transformers considering infrequent occurrence and short duration of such level of GIC. Their results suggest that DC excitation effect by GIC can be reduced choosing proper design and material of transformers.

It is known that strong GICs often occur associated with strong electorojet currents of aurora activities in geomagnetically high latitudes [2, 16, 17]. Japan locates in geomagnetically lower latitude comparing with its geographical latitude as shown in Figure 1. It is believed that power grid problems from GICs hardly occur in Japan because of the country's location at geomagnetically lower latitudes. However, Kappenman [18] noted that large GIC is produced by geomagnetic disturbances driven by intensification of the ring current in low latitude. It was reported that long distance lines of telegraph between Tokyo and outside Tokyo was affected by GIC of a geomagnetic storm on 25 September 1909 in Japan [19]. Hence, it is important to measure GIC even in geomagnetically low latitude like Japan to estimate its effect on power grids. GIC measurement was carried out in Japan between December 2005 and March 2008 with collaboration among National Institute of Information and Communications Technology (NICT), Hokkaido Electric Power Co., and Solar-Terrestrial Environment Laboratory (STEL), Nagoya University [20]. This report is based on the result of that measurement.

Figure 1: Geomagnetic latitude of Japan



Data

Figure 2 shows the 187kV line of Hokkaido Electric Power Co. Electrical current of a transformer of this line was measured at Memanbetsu substation. Direction of the line is south-westward and length of the line is approximately one hundred km. A neutral point for three-phase alternating current of a transformer is grounded directly for protection of the power system. The current of the neutral point is measured using a clamp ammeter. We used one-second GIC data for our analysis.

Kakioka Magnetic Observatory [21], Japan Meteorological Agency routinely has observed geomagnetic field and earth current at Memanbetsu (N43 54'36", E144 11'19", Hokkaido), Kakioka (N36 13'56", E140 11' 11", Ibaraki), and Kanoya (N31 25'27", E130 52'48", Kagoshima) (see Figure 1). We used one-second geomagnetic data at Memanbetsu Observatory nearby the substation to analyze the GIC data. Kakioka Magnetic Observatory provides electric filed data obtained by earth current observations at three stations. We used the one-minute electric field data to study geomagnetically induced electric filed for past large geomagnetic storms, such as the March 13 1989 and the October 29 2003 geomagnetic storms in this paper. We used numerical high-pass filter to remove offsets of the electric field data.

Figure 2: Configuration of measured 187 kV power line

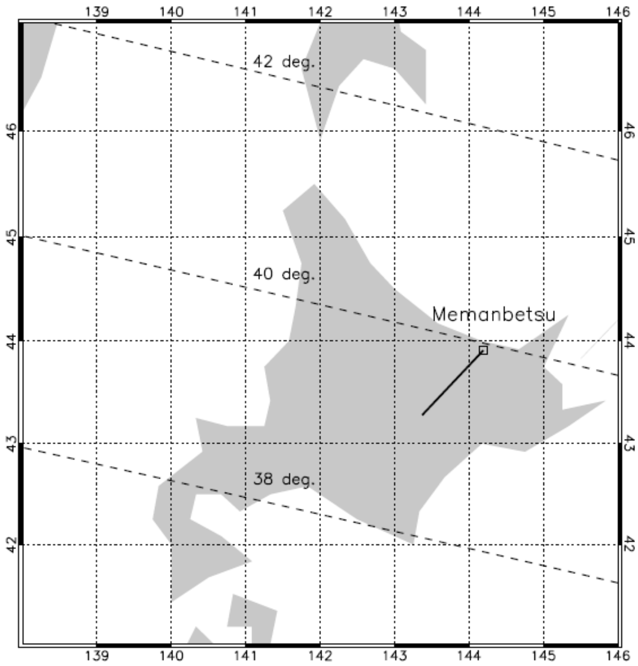


Table 1: List of geomagnetic storms reported from Memanbetsu Magnetic Observatory between December 2005 and March 2008

no.	start (UT)	end (UT)	Δ H (nT)	geomagnetic activity	max. GIC (A)
1	2006/04/04 7.6	2006/04/06 16:00	132	Gradual storm	1.29
2	2006/04/08 22.3	2006/04/10 18:00	106	Gradual storm	0.95
3	2006/04/14 1.6	2006/04/16 17:00	157	Gradual storm	1.58
4	2006/07/27 13:35	2006/07/28 17:00	130	SC storm	1.06
5	2006/08/07 00:35	2006/08/07 21:00	97	SC storm	1.29
6	2006/08/19 10.5	2006/08/20 19:00	103	Gradual storm	1.52
7	2006/11/09 13.0	2006/11/11 21:00	143	Gradual storm	2.23
8	2006/11/30 2.4	2006/11/30 22:00	108	Gradual storm	1.75
9	2006/12/05 22.2	2006/12/07 18:00	101	Gradual storm	1.09
10	2006/12/14 14:14	2006/12/15 24:00	272	SC storm	3.85
11	2007/07/10 18.1	2007/07/11 10.7	100	Gradual storm	0.98
12	2007/07/20 06:16	2007/07/20 13.5	86	SC storm	0.66
13	2007/11/20 09:08	2007/11/20 21:17	105	SC storm	1.13
14	2007/12/17 02:52	2007/12/17 17:24	103	SC storm	0.77
15	2008/03/08 07:18	2008/03/10 24:00	118	Gradual storm	0.88

Table 2: List of five largest GIC events measured between December 2005 and March 2008.

no.	date	max. GIC (A)	geomagnetic activity
1	2006/12/15	3.85	SC storm
2	2006/11/10	2.23	Gradual storm
3	2006/11/30	1.75	Gradual storm
4	2006/07/10	1.59	Sudden Impulse
5	2006/04/14	1.58	Gradual storm

GIC Events and Geomagnetic Activities

Table 1 is a list of geomagnetic storms reported from Memanbetsu between December 2005 and March 2008. Table 1 also shows maximum values of GIC associated with geomagnetic storms. Only fifteen geomagnetic storms were observed between December 2005 and March 2008 because of low solar activity in solar minimum of cycle 23.

Table 2 is a list of the five largest GIC events between December 2005 and March 2008. Almost intense events are associated with geomagnetic storms. According to our measurement, GIC events occurred with various kinds of geomagnetic activities although intense GIC events are associated with geomagnetic storms. Our measurement in Hokkaido also suggests that variations of GIC have a good correlation with east-west component (By) of geomagnetic variations. Details on them are reported below.

GIC Event Associated with a Geomagnetic Storm on 25 December 2006

Figure 3 shows the most intense GIC occurred associated with a geomagnetic storm and north-south (Bx), east-west (By), and vertical (Bz) components of geomagnetic variations observed at Memanbetsu. This geomagnetic storm occurred at 1414UT on 14 December, 2006 and was the largest one during our measurement period. The source of this geomagnetic storm was the full halo coronal mass ejection (CME) associated with the X3.4/4B flare (S06W24) at 0214 UT on 13 December [22]. The disturbance took only 36 hours to travel from the Sun to the Earth. The maximum value of GIC was measured during main phase of this geomagnetic storm. According to Figure 3, the variation of By component shows a good correlation with the variation of GIC.

GIC Event Associated with Sudden Change of Geomagnetic Field on 9 July, 2006

Kappenman [23] noted that a large impulsive geomagnetic variation of sudden storm commencement (SSC) on 24 March 1991 produced the largest GIC measured in the US and that impulsive geomagnetic variations by interplanetary shocks are a potential driver of large GICs. Figure 4 is an example of GIC associated with a Sudden Impulse (SI) event observed at 2134 UT on 9 July, 2006. A source of this SI is caused by an arrival of an interplanetary shock associated with a partial halo CME. This partial halo CME occurred with a M2.5/2F long duration flare (S11W32) in AR0898 at 0823 on 6 July and with Type II and IV radio bursts. GOES satellite observed an enhancement of flux of solar energetic proton with energy more than 10 MeV.

GIC Event Associated with a Substorm Activity

At high latitudes, a GIC event is produced by an enhancement of electrojet current associated with aurora activities, or substorm activities [2, 16, 17]. At middle latitudes, GICs were often observed associated with “positive bays” according to our measurement. It is known that substorms produce positive bays at middle latitudes [24]. Our result suggests that even at middle latitudes, aurora activities are a source of GICs. Figure 5 is an example of GIC event produced by a positive bay on 20-21 November, 2007.

Figure 3: GIC event associated with the geomagnetic storm on 15 December 2006 (top panel) and Bx (second panel) , By (third panel), Bz (bottom panel) components of geomagnetic variations at Memanbetsu

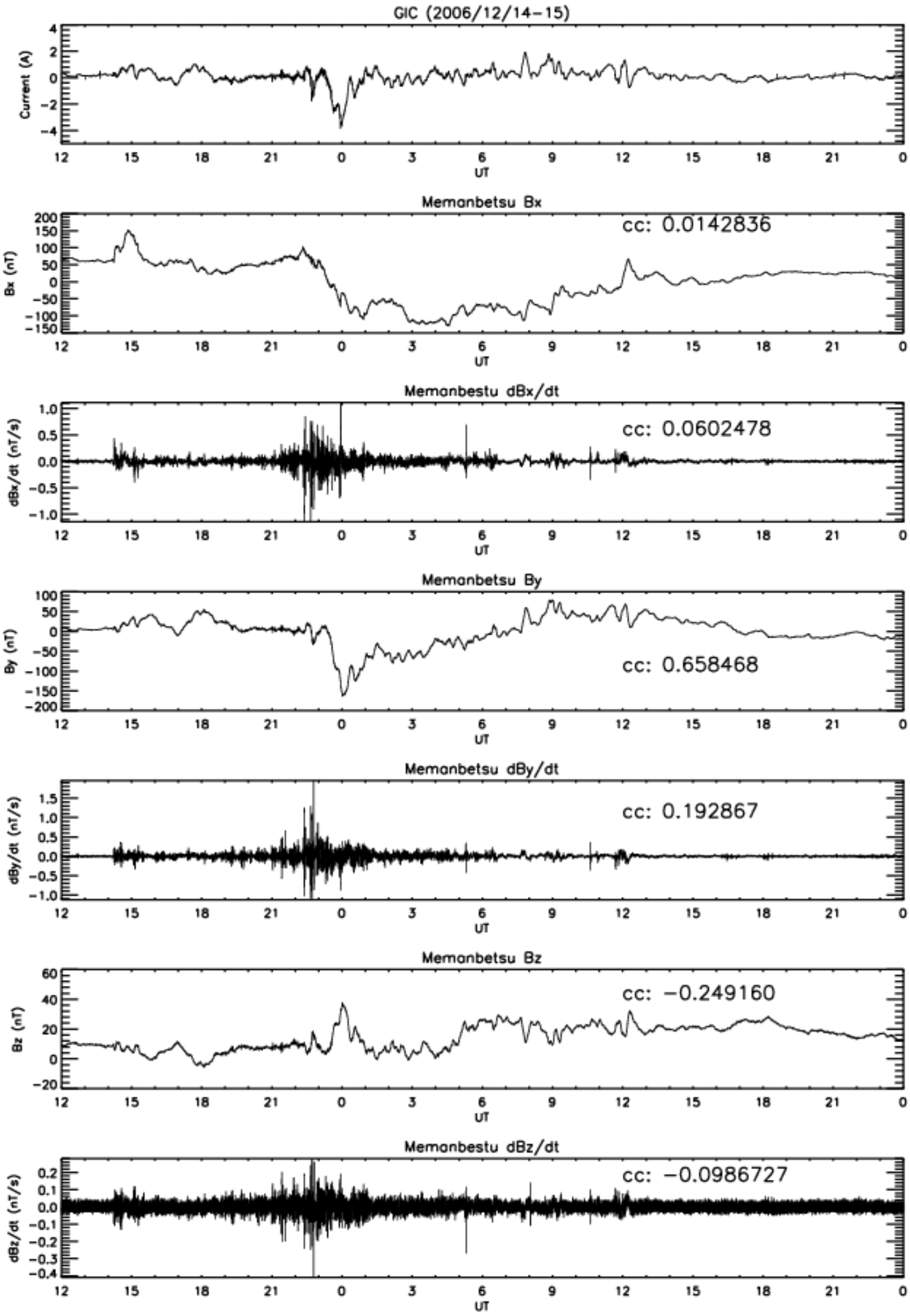


Figure 4: GIC event associated with the SI at 2134UT on 9 July 2006 and Bx, By, and Bz components of geomagnetic variations at Memanbetsu

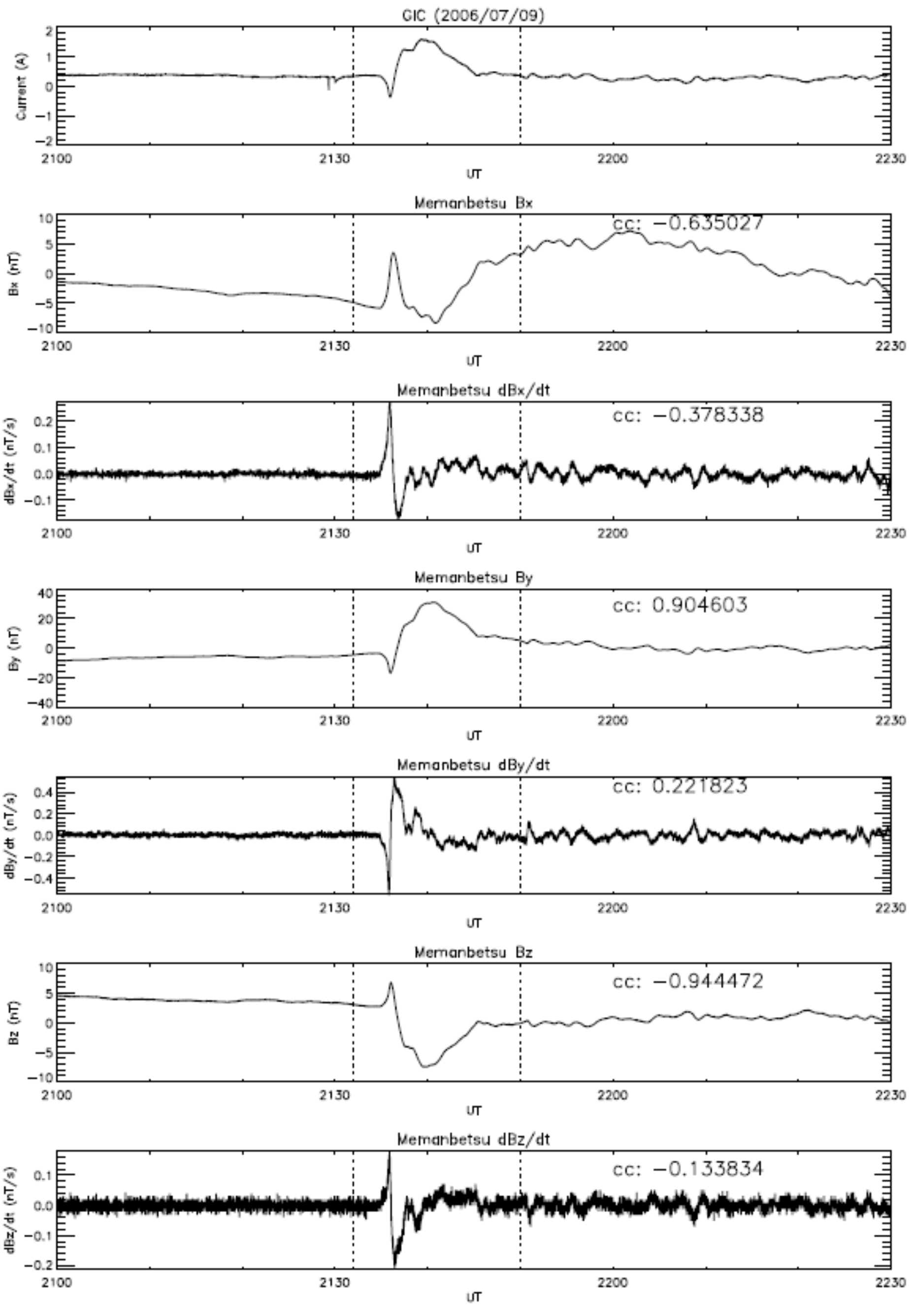
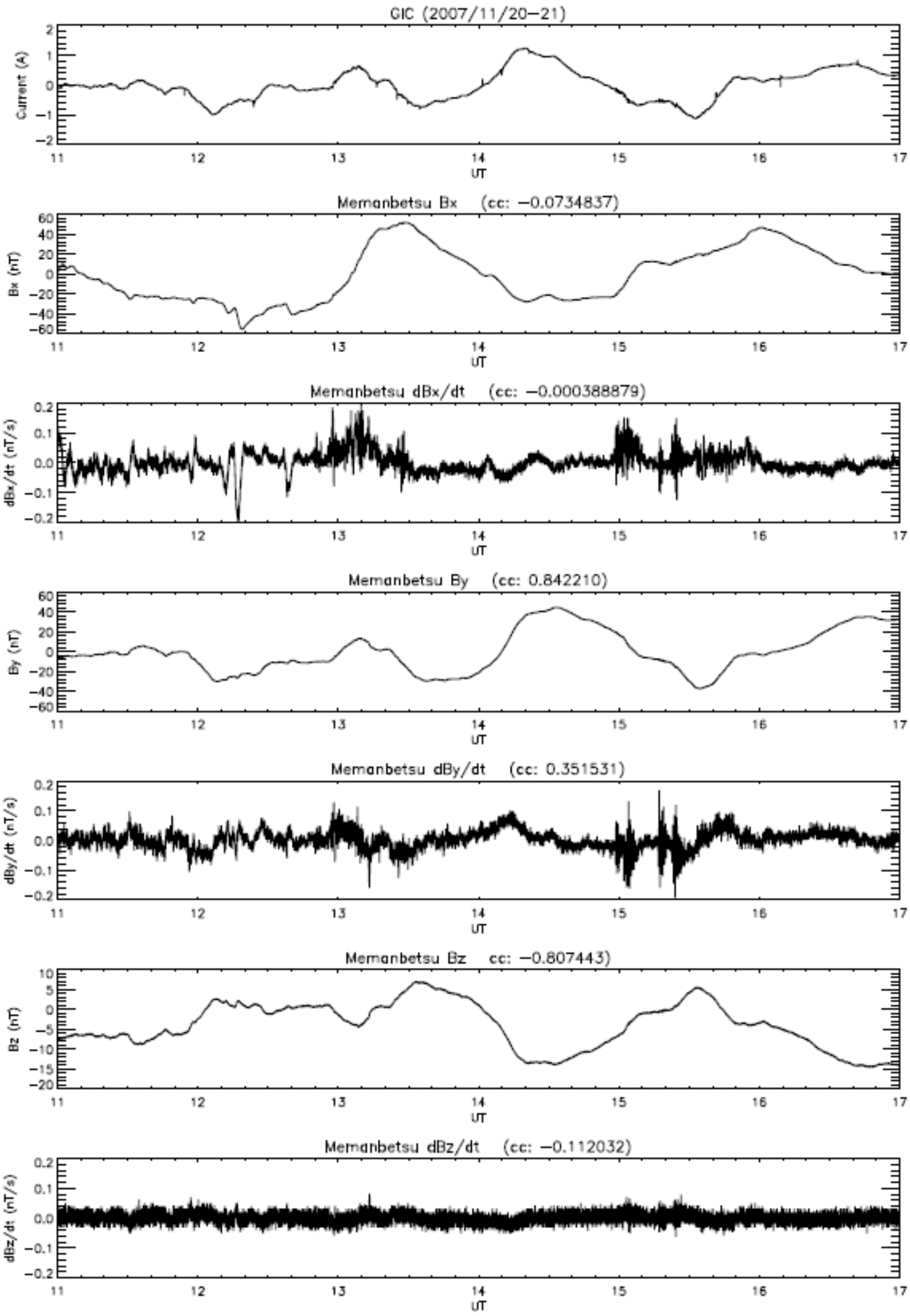
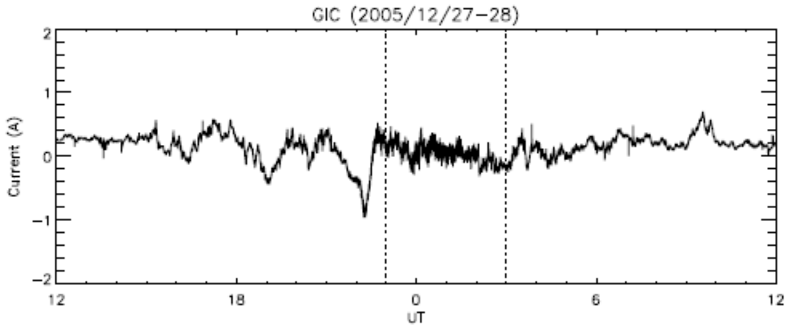


Figure 5: GIC event associated with the bay disturbance on 20-21 November 2007 and Bx, By, and Bz components of geomagnetic variations at Memanbetsu



GIC Event Associated with a Pc5 Range Geomagnetic Pulsation

Figure 6: GIC event associated with the Pc5 pulsation on 27-28 December 2005 and Bx, By, and Bz components of geomagnetic variations at MMB



Ultra-low-frequency (ULF) pulsation with 150-600 s periods is called Pc5 range geomagnetic pulsation. The Pc5 pulsation is enhanced by high speed solar wind from coronal holes [25]. It is reported that this Pc5 pulsation produces small amplitude fluctuation of GICs [26]. Figure 6 is an example of a GIC event produced by the Pc5 pulsation on 27-28 December, 2005. This event occurred in high-speed solar wind from coronal hole. The effect of the pulsations on power grids seems to be small because of their small amplitudes. However, it might electrically erode metallic pipe lines as long-term influence.

Local Time and Seasonal Dependence

Figure 7: Local time and seasonal dependence of occurrence of GIC events

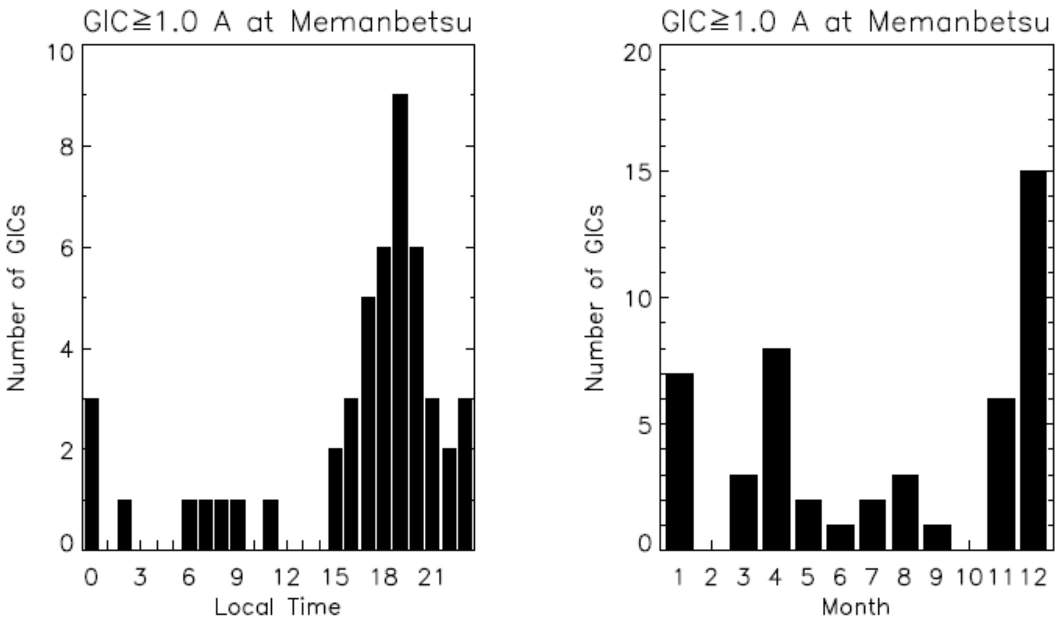
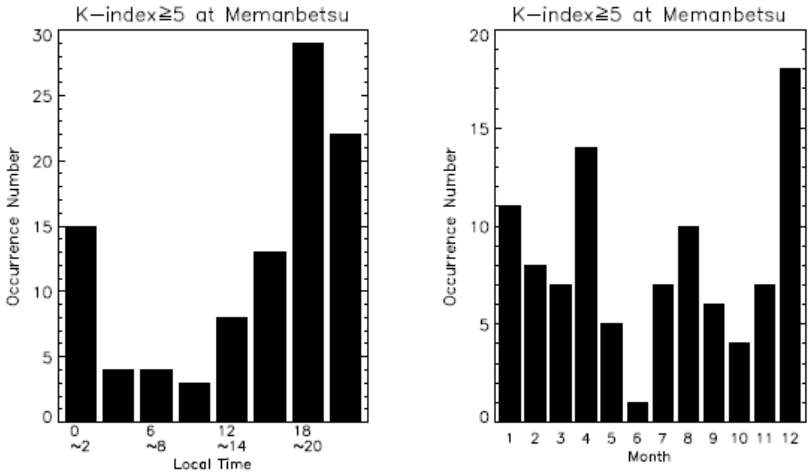


Figure 8: Local time and seasonal dependence of occurrence of Memanbetsu K-index equal to or more than five



We selected data periods with measured current exceeding one ampere as a GIC event. Figure 7 is a local time dependence (left) and a seasonal dependence (right) of occurrence of the GIC events. Figure 8 shows local time and seasonal dependences of occurrence of Memanbetsu K-index equal to or more than five. The GIC events are frequently observed in the evening and there are enhancements of GIC events in April and December. These tendencies correspond with occurrence of geomagnetic activities during the measurement period. According to the goodness-of-fit test, occurrences of GIC events shown in Figure 7 are not random.

Estimation of GIC Based on the Measurements

Figure 9: Scatter plot of maximum H variation of geomagnetic storms and maximum value of GICs

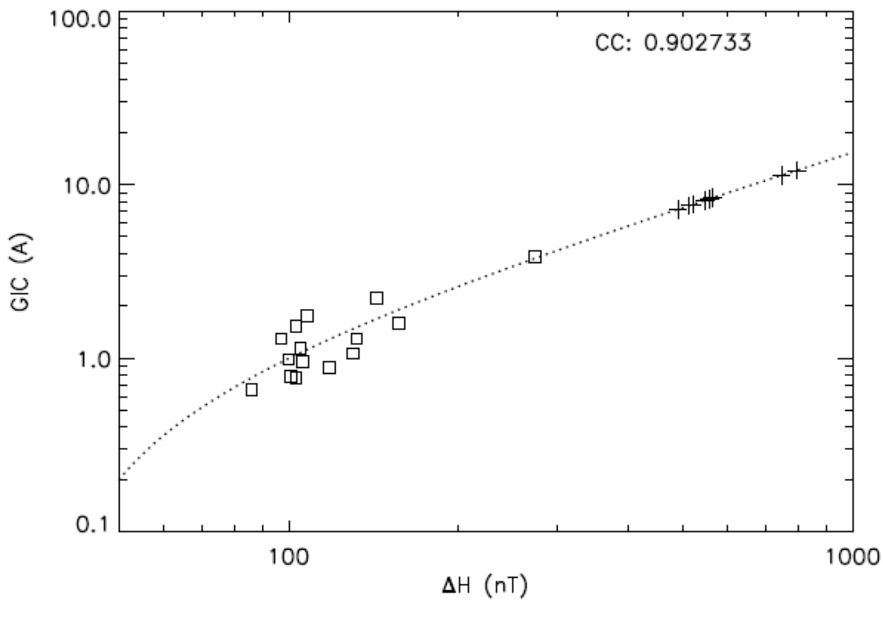


Table 3: List of ten largest geomagnetic storms reported from Memanbetsu Magnetic Observatory since 1957

no.	time (UT)	duration (hour)	Δ H (nT)	SC (nT)	estimated max. GIC (A)
1	1982/07/13 16:17	------	796	148	12.1
2	1989/03/13 01:27	68.6	747	94	11.3
3	1958/07/08 07:48	51.2	565	165	8.4
4	1959/07/15 08:02	42.0	563	92	8.4
5	1958/02/11 01:26	52.6	557	50	8.3
6	1967/05/25 12:35	103.4	547	202	8.1
7	2000/07/15 14:36	27.4	520	180	7.7
8	1972/08/05 14:00	52.0	520	63	7.7
9	2003/10/29 06:11	------	513	112	7.6
10	1960/11/12 13:48	56.2	490	48	7.2

Figure 9 is a scatter plot of maximum value of horizontal variation of geomagnetic storms and magnitude of maximum GIC shown in Table 1. There is approximately liner relation between magnitude of geomagnetic storm and max. GIC. We obtained equation (1) by the least mean square method.

$$\text{maximum GIC (A)} = 0.0159 \times \Delta\text{H (nT)} - 0.598 \qquad (1)$$

Table 3 is historical ten geomagnetic storms since 1957 reported from Memanbetsu. We estimated maximum GIC using equation (1). The estimated maximum GIC is 11.3 A for the March 13 1989 storm and is 7.6 A for the October 29 2003 storm, respectively. Maximum value of GIC: approximately 12 A is expected for the July 13 1982 storm, the largest geomagnetic storm during approximately fifty years shown Table 3.

March 13 1989 Geomagnetic Storm

Figures 10 and 11 show north-south and east-west components of induced electric fields observed at Memanbetsu, Kakioka, and Kanoya in the March 13 1989 storm, respectively. Electric power blackout occurred in Canada associated with this storm [2, 11, 12]. Geomagnetic fields of north-south and east-west components show similar variations among Memanbetsu, Kakioka, and Kanoya. Variations of north-south component of the electric fields decrease in order of Memanbetsu, Kakioka, and Kanoya. However, variations of east-west component of the electric fields decrease in order of Kakioka, Kanoya, and Memanbetsu. According to Figures 10 and 11, electric fields at Kakioka and Kanoya show similar variations. However, electric field at Memanbetsu shows different variation from them. East-west component of electric field of Kakioka shows the largest variation in three stations. Maximum strength of one-minute electric field data in Memanbetsu, Kakioka, and Kanoya are 0.18 V/km, 0.36 V/km, and 0.12 V/km, respectively.

October 29 2003 Geomagnetic Storm

Figures 12 and 13 show north-south and east-west components of induced electric fields observed in the October 29 2003 storm, respectively. In this storm, electric power blackout occurred in southern Sweden [13, 14]. East-west component of electric fields of Kakioka shows the largest variation in three stations. Maximum strength of one-minute electric field data in Memanbetsu, Kakioka, and Kanoya are 0.13 V/km, 0.49 V/km, and 0.14 V/km, respectively.

Figure 10: North-south component of electric fields observed at Memanbetsu, Kakioka, and Kanoya in the March 13 1989 storm

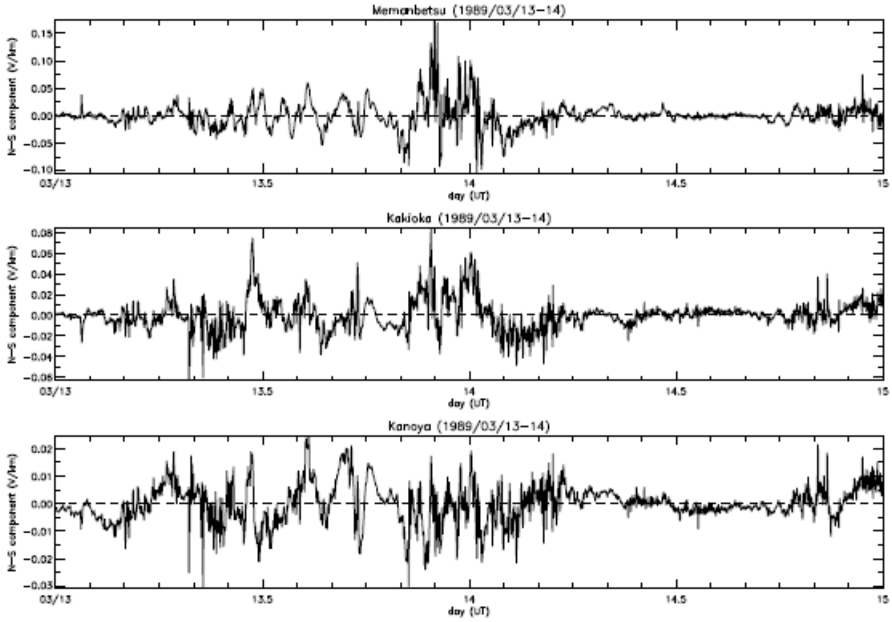


Figure 11: East-west component of electric fields observed at Memanbetsu, Kakioka, and Kanoya in the March 13 1989 storm

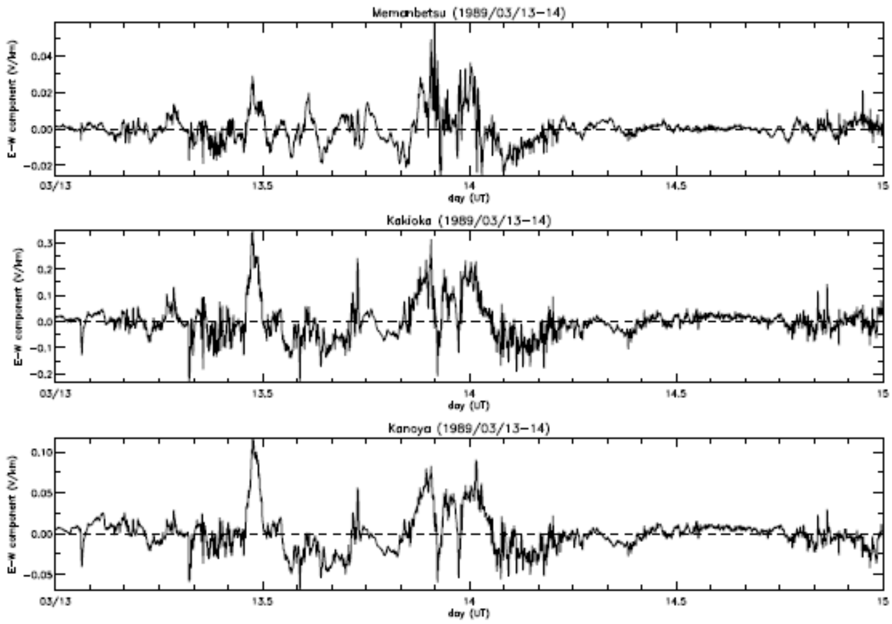


Figure 12: North-south component of electric fields observed at Memanbetsu, Kakioka, and Kanoya in the October 29 2003 storm

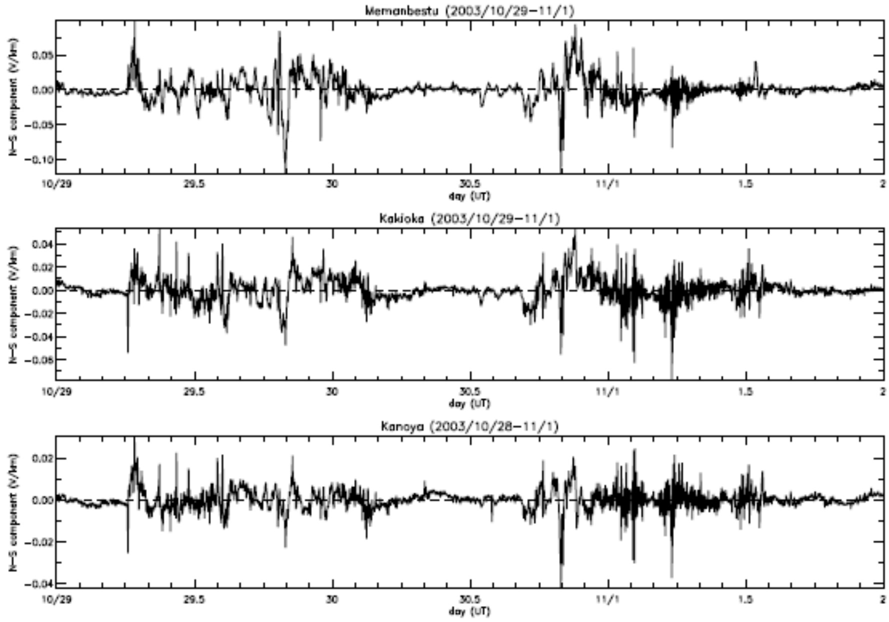
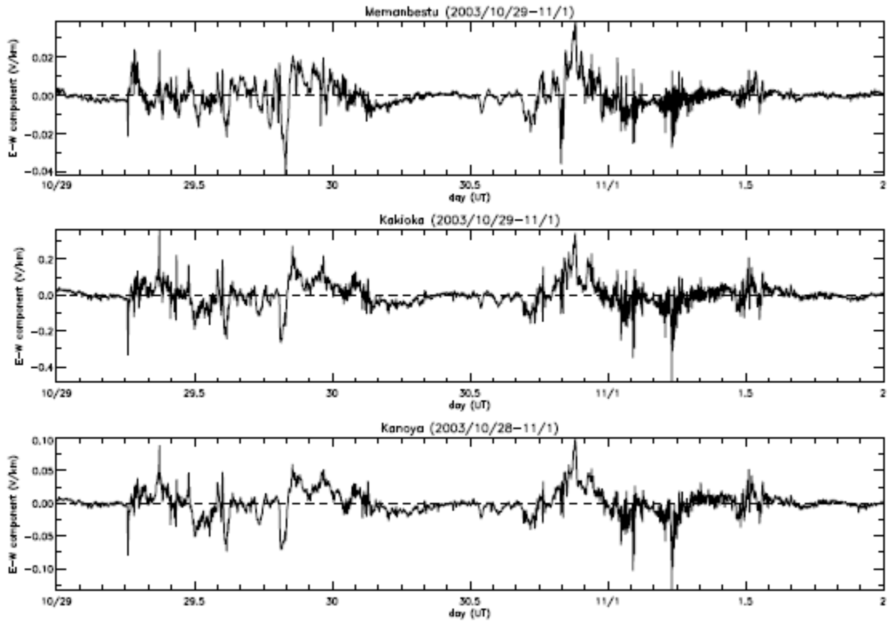


Figure 13: East-west component of electric fields observed at Memanbetsu, Kakioka, and Kanoya in the October 29 2003 storm



Space Weather Center in Japan

In Japan, NICT has operated a space weather center as one of the regional warning centers of the International Space Environment Service (ISES) and delivers space weather forecast and information to users through web page (http://swc.nict.go.jp/index_e.php), e-mail, and so on [27].

NICT was originally named the Radio Research Laboratories (RRL) between 1952 and 1988, and then was named the Communications Research Laboratory (CRL) between 1988 and 2004. Present NICT started by reorganization of CRL since 2004. RRL (present NICT) has made researches and forecasts of HF radio communication since 1952 because HF radio communication was a main method for long distance communication in those days. However, artificial satellites and marine cables have gradually become major methods of long distance communication. NICT started a space weather research project in 1988 based on the forecast service of HF radio communication [28].

Figure 14: NICT space weather forecast center

Summary

We reported the result of approximately two and half year GIC measurement in Japan. It is believed that power grid trouble by GIC is hardly occurring in Japan because of geomagnetically lower latitudes. According to past study [7], it is possible to reduced DC excitation effect of transformers by GIC using proper design and material for transformers. However, there is a possibility of an intense GIC if an extremely large geomagnetic disturbance occurs [17]. Our study enables to provide an estimate for such an extreme event. Our measurement also suggests that underground conductivity is an important factor on GIC [20]. In high underground conductivity regions, time variation of GIC corresponds with that of geomagnetic field rather than time derivative of geomagnetic field and amplitude of GIC tends to become smaller. This dependence of underground conductivity is shown by modeling [29, 30]. Hence, a production of a map of underground conductivity is an important issue to estimate GIC hazards.

Acknowledgement

We thank to Hokkaido Power Co for measurement of GIC at the Memanbetsu substation. We also thank Kakioka Magnetic Observatory, Japan Metrological Agency for providing us geomagnetic and electric fields data, Memanbetsu K-index, the lists of geomagnetic storms and bay disturbances of Memanbetsu Magnetic Observatory.

References

[1] L. J. Lanzerotti, "Space Weather Effects on Technologies" in Space Weather, Geophys. Monogr. Ser., vol.125, edited by P. Song, H. Singer, and G. Siscoe, pp.11-22, 2001

[2] D. H. Boteler, "Space Weather Effects on Power Systems" in Space Weather, Geophys. Monogr. Ser., vol.125, edited by P. Song, H. Singer, and G. Siscoe, pp.347-352, AGU, Washington DC, 2001

[3] R. Pirjola, A. Viljanen, A. Pulkkinen, S. Kilpua, and O. Amm, "Ground effects of space weather" in Effects of Space Weather on Technology Infrastructure (Edited by I.A. Daglis), pp.257-299, NATO Science Series, Kluwer Academic Publishers, 2004

[4] Severe Space Weather Events –Understanding Societal and Economic Impacts: Workshop Reports, The National Academies Press, 2008

[5] J. G. Kappenman, V. D. Albertson, and N. Mohan, "Current transformer and relay performance in the presence of geomagnetically-induced currents", IEEE Transactions on Power Apparatus and Systems, PAS-100(3), pp.1078-1088, 1981

[6] J. D. Aspnes and R. P. Merritt, "Effect of DC excitation on instrument transformers", IEEE Transactions on Power Apparatus and Systems, PAS-102(11), pp.3706-3712, 1983

[7] N. Takasu, T. Oshi, F. Miyashita, S. Saito, and Y. Fujiwara, "An experimental analysis of excitation of transformers by geomagnetically induced currents", IEEE Transactions on Power Delivery, 9(2), pp.1173-1179, 1994

[8] J. G. Kappenman, J.G., "An introduction to power grid impacts and vulnerabilities from space weather" in Space Storms and Space Weather Hazards (Edited by I.A. Daglis), pp.335-361, NATO Science Series, Kluwer Academic Publishers, 2000

[9] J. G. Kappenman, "Advanced geomagnetic storm forecasting for the electric power industry" in Space Weather, Geophys. Monogr. Ser., vol.125, edited by P. Song, H. Singer, and G. Siscoe, pp.353-358, 2001

[10] NERC 2012 Special Reliability Assessment, Interim Report, "Effects of Geomagnetic Disturbances on the Bulk Power System", February 29, 2012, http://www.nerc.com/files/2012GMD.pdf

[11] D. H. Boteler, R. M. Shier, T. Watanabe, and R. E. Horita, "Effects of geomagnetically induced currents in the B. C. Hydro 500 kV system", IEEE Transactions on Power Apparatus and Systems, 4(1), pp.818-823, 1989

[12] J. G. Kappenman, "Effects of Geomagnetic Disturbances on Power Systems", Power Engineering Review, IEEE , 9(10), pp.15-20, 1989

[13] J. G. Kappenman, "An overview of the impulsive geomagnetic field disturbances and power grid impacts associated with the violent Sun-Earth connection events of 29-31 October 2003 and a comparative evaluation with other contemporary storms", Space Weather, 3(8), S08C01, doi:10.1029/2004SW000128, 2005

[14] A. Pulkkinen, S. Lindahl, A. Viljanen, and R. Pirjola, "Geomagnetic storm of 29-31 October 2003: Geomagnetically induced currents and their relation to problems in the

Swedish high-voltage power transmission system", Space Weather, 3(8), S08C03, doi:10.1029/2004SW000123, 2005

[15] The IEEE Transmission and Distribution Committee Working Group on Geomagnetic Disturbances and Power System Effects, "Geomagnetic disturbance effects on power systems", IEEE Transactions on Power Delivery, 8 (3), pp.1206-1216, 1993

[16] A. W. P. Thomson, E. B. Dawson, and S. J. Reay, "Quantifying extreme behavior in geomagnetic activity"

[17] A. Pulkkinen, E. Bernabeu, J. Eichner, C. Beggan, and A. W. P. Thomson, "Generation of 100-year geomagnetically induced current scenarios", Space Weather, Vol.10, S04003, doi:10.1029/2011SW000750, 2012

[18] J. G. Kappenman, "Space weather and the vulnerability of electric power grids" in Effects of Space Weather on Technology Infrastructure (Edited by I.A. Daglis), pp.257-299, NATO Science Series, Kluwer Academic Publishers, 2004

[19] T. Uchida, Earth current on 25 September 1909, The Journal of the Institute of Electrical Engineers of Japan, 29 (255), pp.701-721, 1909 (in Japanese)

[20] S. Watari, M. Kunitake, K. Kitamura, T. Hori, T. Kikuchi, K. Shiokawa, N. Nishitani, R. Kataoka, Y. Kamide, T. Aso, Y. Watanabe, and Y. Tsuneta, "Measurements of Geomagnetically Induced Current in a Power Grid in Hokkaido, Japan", Space Weather, 7, S03002, doi:10.1029/2008SW000417, 2009

[21] Kakioka Magnetic Observatory, http://www.kakioka-jma.go.jp/en/index.html

[22] H. Isobe, M. Kubo, T. Minoshima, K. Ichimoto, Y. Katsukawa, T. D. Tarbell, S. Tsuneta, T. E. Berger, B. Lites, S. Nagata, T. Shimizu, R. A. Shine, Y. Suematsu, A. M. Title, "Flare ribbons observed with G-band and Fe I 6302A Filters of the solar optical telescope on board Hinode, Publ. Astron. Soc. Jpn., 59, S807-813, 2007

[23] J. G. Kappenman, "Storm sudden commencement events and the associated geomagnetically induced current risks to groundbased systems at low-latitude and midlatitude locations", Space Weather, 1(3), 1016, doi:10.1029/2003SW000009, 2003

[24] G. Rostoker, S.-I. Akasofu, J. Foster, R. A. Greenwald, Y. Kamide, K. Kawasaki, A. T. Y. Lui, R. L. McPerron, and C. T. Russell, "Magnetospheric substorms: Definition and signatures", J. Geophys. Res., 85(A4), pp.1663-1668, doi:10.1029/JA085iA04p01663, 2005

[25] W. J. Hughes, "Magnetospheric ULF waves: A tutorial with a historical perspective" in Solar Wind Sources of Magnetospheric Ultra-Low-Frequency Waves, Geophys. Monogr. Ser., vol.81, edited by M. J. Engebretson, K. Takahashi, and M. Scholer, pp.1-11, AGU, Washington DC, 1994

[26] A. Pulkkinen and R. Kataoka, "S-transform view of geomagnetically induced currents during geomagnetic superstroms", Geophys. Res. Lett., 33, L12108, doi:10.1029/2006GL025822, 2006

[27] S. Watari, "Space weather center in Japan", Adv. Space Res., 42(9), pp.1445-1449, 2008

[28] K. Marubashi, "The space weather forecast program", Space Sci. Rev., 51(1-2), pp.197-214, 1989

[29] R. Pirjola, D. Boteler, and L. Trichtchenko, "Ground effects of space weather investigated by the surface impedance", Earth Planets Space, 61, pp.249-261, 2009

[30] A. Pulkkinen, R. Kataoka, S. Watari, and M. Ichii, “Modeling geomagnetically induced currents in Hokkaido, Japan”, Advances in Space Research, 46, 1087-1093, doi:10.1016/j.asr.2010.05.024, 2010

Biographies

Shinichi Watari is the Research Manager of Space Weather and Environment Informatics Laboratory in National Institute of Information and Communications Technology (NICT). NICT has hosted the Regional Warning Canter (RWC) of the International Space Environment Service (ISES). In 1988, NICT has started Space Weather Project. Shinichi Watari joined the Radio Research Laboratories (present NICT) in 1984 and was involved the Space Weather Project since its beginning. He is interested in solar sources of geomagnetic disturbances and studied them using soft X-ray solar images taken by Yohkoh satellite. He found that interplanetary CMEs were sometimes observed without remarkable activities in soft X-ray solar images. Between 1994 and 1995, he worked in the NOAA/Space Environment Center (present Space Weather Prediction Center). He received a Doctor of Science in 1999 on the study of solar sources of interplanetary disturbances.