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Research Paper

Time Derivative of The Horizontal Geomagnetic Field As A Proxy For Geomagnetically Induced Currents (GICS) Within African Latitudes

Madu Onyeka Emmanuel[1] and Obiekezie Theresa Nkechi[1,2]
[1]*Department of Physics and Industrial Physics, Faculty of Physical Sciences, Nnamdi Azikiwe University, Awka.*
[2]*Ministry of Youth Empowerment and Creative Economy, Awka, Anambra State.*
**Corresponding Author: Madu Onyeka Emmanuel.*

ABSTRACT
Data from four African stations were used to calculate the time derivative of the horizontal geomagnetic field as a proxy for geomagnetically induced currents (GICs). Dst and Kp indices values < -100 nT and ≥ 7 respectively were used to characterize stormy days. The analysis was carried out using one-minute values of Northward, (X) component, and Eastward, (Y) component of the geomagnetic field values. The results of this study confirm the presence of GICs in the African latitudes. These currents are seen to be superimposed on solar disturbances.
KEYWORDS*: Geomagnetic field, Derivative, Induced Currents, Storm and Africa.*

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I.INTRODUCTION

Solar disturbance such as solar flare, coronal mass ejection and prominences causes fluctuating currents in the ionosphere and magnetosphere. These currents produce geomagnetic variations and induce a geoelectric field which drives geomagnetically induced currents (GICs) also known as telluric currents into ground technological systems [1]. Geomagnetically induced currents (GICs) can yield damages to pipelines, railways, cables and other architectures which have long electrical conductor systems. For example, the end-to-end voltages associated with GICs can be very large along power lines and trans-oceanic submarine communication cables. Buried pipelines may suffer from serious corrosion of the steel due to GIC [2]. One of the famous damages is the collapse of Hydro-Québec power grid during the great magnetic storm on March 13, 1989. [3], reported that the electrical power supply was interrupted for many hours and voltage instability which resulted in safety features tripping the transmission system costed $6 500 000 in material damages alone and that the system collapse followed a sudden large variation of geomagnetic field (e.g., about 1000nT decrease in the north component within several minutes). The large GIC made the system unstable since a number of static compensators essential for maintaining dynamic stability, started tripping one after the other. Another example of GIC was recorded in Southern Finland [4], [5].

GICs are mostly noticed at the high latitude regions, the observed variations are related to the increase in the electrojets during the high ionospheric convection conditions and substorms [1]. GICs have been regularly measured in Canadian, Finnish and Scandinavian power grids and pipelines since the 1970s. GIC of thousands ampere have also been recorded at mid-latitudes during major geomagnetic storms. There may even be a risk to low latitude areas especially during a storm commencing suddenly because of the high, short-period rate of change of the field that occurs on the day side of the Earth. [6] and [7] established that auroral electrojet, ionospheric current and magnetospheric current systems are considered to be one of the principal causes of the geomagnetic disturbances leading to GIC.

This study aims at investigating the time derivative of the horizontal geomagnetic field as a proxy for Geomagnetically Induced Currents (GICs) within the African Latitudes.

II. MATERIALS AND METHODS

The data employed in this research consists of the X and Y components of the geomagnetic field, the Kp and Dst indices. These data were collected from the website of the World Data Centre Kyoto, Japan (http:/wdc.kugi.kyoto-u.ac.jp/index.html) on International Disturbed Days (IDDs) between 2001 and 2006 with at least one value of Dst index value ≤ -100 nT, and at least one value of Kp index ≥ 7 for four African stations namely: Addis Ababa, AAE (9.035^0, 38.770^0); Bangui, BNG (4.333^0, 18.566^0); Hermanus, HER (-34.425^0, 19.225^0); M'Bour, MBO (14.380^0, 343.030^0). Table 1 shows the geographic location of the stations.

Table 1: Study stations and their locations

S/No	Stations	Abbreviations	Locations in Africa	Geographic locations		Geomagnetic locations	
				Lat. (◦)	Long (◦)	Lat. (◦)	Long (◦)
1	Addis Ababa	AAE	East	9.035	38.770	5.35	112.53
2	Bangui	BNG	Central	4.333	18.566	4.04	91.90
3	Hermanus	HER	South	-34.425	19.225	-34.00	85.27
4	M'Bour	MBO	West	14.380	343.030	19.59	58.13

After the selection of the disturbed days, the one minute values of the H-component of the geomagnetic field for the disturbed days was calculated using Equation 1:

$$H = \sqrt{X^2 + Y^2} \qquad 1$$

Where X= one-minute northward component of the geomagnetic field and Y= one-minute eastward component of the geomagnetic field. The time derivative (temporal variation) of the H-component was calculated by subtracting successive values of H and dividing by the sampling interval as shown in Equation 2:

$$\frac{dH}{dt} = \frac{H_{t+1min} - H_t}{1\,min} \qquad 2$$

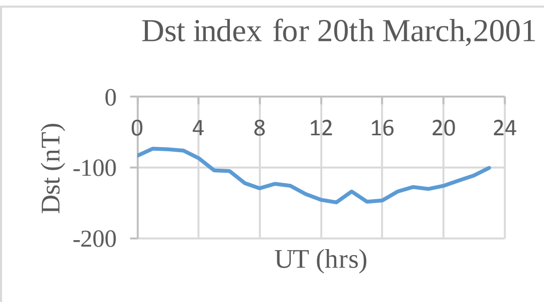
Where H_t = value of H at a minute t, H_{t+1min} = value of H at the minute immediately after the minute t, 1 minute= sampling interval.

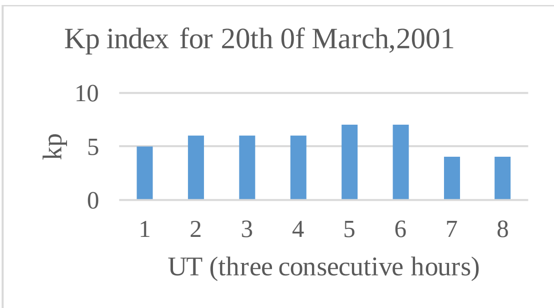
III. RESULTS AND DISCUSSION

The selection yielded the results of the following geomagnetic stormy days: 20th March 2001, 17th August 2001, 21st October 2001, 6th November 2001, 29th October 2003 and 15th December 2006.

3.1 20th March 2001 Storm

Fig.1 depicts the response plot for the storm of 20th March 2001. An intense storm with a minimum Dst value of -149 nT was observed at 13.00 UT with the Kp index for the day attaining a maximum of 7.33. The effect of this storm was clearly observed by the computed values of dH/dt attaining a maximum value of 5.01 nT/min in Addis Ababa (AAE) at 14:13 UT, and a maximum value of 3.01nT/min in Bangui (BNG) at 9:34 and 14:06 UT and 6.29 nT/min in Hermanus (HER) at 15:59 UT and 6.41 nT/min in M'Bour at 12:50 UT. The total number of minutes for which │dH/dt│> 5 nT/min in AAE is 1 and 2 minutes in HER and 4 minutes in MBO, following [8] and [9] these signify the total number of minutes for which GIC flowed in conductive media like transformers, transmission lines etc. around the vicinity of the stations, while there was an absence of GICs in BNG. These results are clearly shown in Table 2. The total number of minutes for which │dH/dt│ > 30 nT/min in the four African stations is zero. In line with the works of [8], [9] and [10] it could be deduced that the GIC associated with the storm of 20th March, 2006 is not big enough to cause any damage in conductive media within their terrestrial environment. This is clearly shown in Table 3.





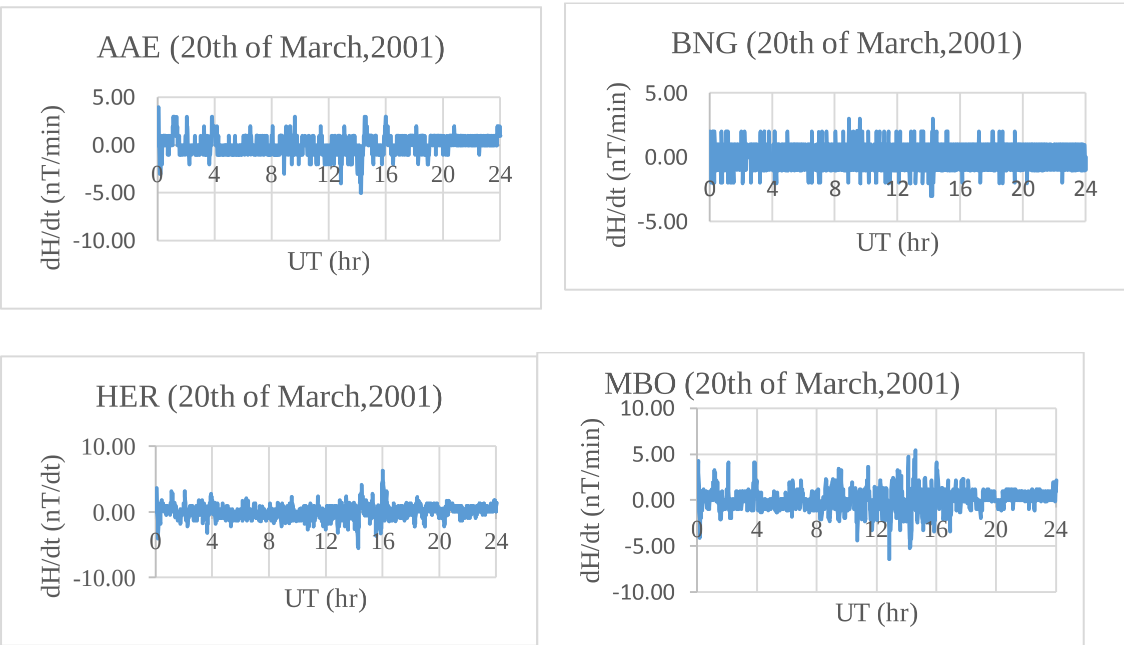


Fig. 1: Magnetic response plot for 20th March 2001.

Table 2: Total number of minutes for which $\left|{dH}/{dt}\right| > 5$ nTmin^{-1}

Date	Total number of minutes when │dH/dt│> 5 nT/min			
	AAE	BNG	HER	MBO
20/03/2001	1	0	2	4
17/08/2001	40	23	11	37
21/10/2001	53	44	30	45
06/11/2001	305	95	82	100
29/10/2003	562	452	465	522
15/12/2006	101	3	6	7
Total	1062	617	596	715

Table 3: Total number of minutes for which $\left|{dH}/{dt}\right| > 30$ nTmin^{-1}

Date	Minimum Dst index(nT)	Maximum Kp index	Number of minutes when │dH/dt│>30nT/min			
			AAE	BNG	HER	MBO
20/03/2001	-149	7.33	0	0	0	0
17/08/2001	-105	7.00	2	0	0	0
21/10/2001	-187	7.67	1	1	1	1
06/11/2001	-292	8.67	4	1	1	1
29/10/2003	-350	9.00	72	15	20	40
15/12/2006	-162	8.33	2	0	0	0
Total			81	17	22	42

3.2 17th of August 2001 Storm

Fig. 2 shows the effect of an intense storm with a minimum Dst of -105 nT/min at 21:00 UT on the 17th of August 2001 with the Kp index for the day attaining a maximum value of 7.00 respectively. The effect of this intense storm was further observed by the computed values of │dH/dt│ attaining maximum values of 32.90 nT/min in AAE at 11:03 UT, 20.11 nT/min in Bangui at 11:03 UT, 12. 17 nT/min in Hermanus at 23:12 UT and 22.04 nT/min in M'Bour at 11:03 UT. The total number of minutes for which │dH/dt│> 5 nT/min is 40 minutes for AAE and 23 minutes for BNG, 11 minutes for HER and 37 minutes for M'Bour, following [8] and [9] these signify the total number of minutes for which GIC flowed in the conductive media around the vicinity of the stations on the 17th of August, 2001. These are clearly summarized in Table 2. The total number of time which │dH/dt│> 30 nT/min is 2 minutes in AAE. In line with the works of [8], [9] and [10] these signify the total number of time for which conductive media in Addis Ababa was subjected to GICs that could cause undesirable consequences, while the total number of time which │dH/dt│> 30 nT/min in the other three stations is zero for each of these stations, hence conductive media within the study stations were not overloaded due to GICs. These are shown in Table 3.

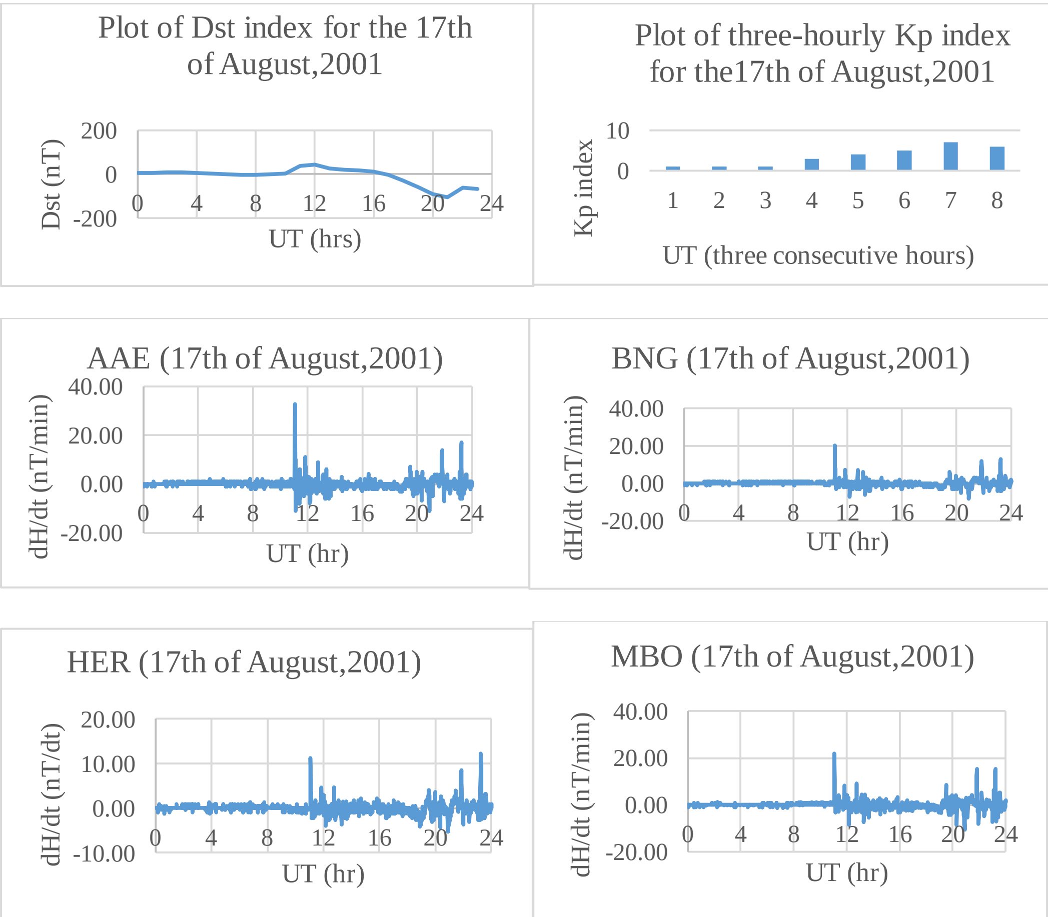


Figure 2: Plot of magnetic response for 17th August, 2001.

3.3 21st October 2001 Storm.

Fig. 3 depicts response plot for the storm of 21st October 2001 with an intense storm of minimum Dst -187 nT at 21:00 UT and a maximum Kp index of 7.67. The effect of this intense storm was observed by the computed values of │dH/dt│ attaining maximum values of 47.88 nT/min in Addis Ababa at 16:48 UT, 34.16 nT/min in Hermanus at 16:48 UT and 63.47 nT/min in M'Bour at 16:48 UT, an evening and night-time enhancement of the time derivative of the horizontal geomagnetic field was also observed. The total number of minutes for which │dH/dt│> 5 $nTmin^{-1}$ is 53 for AAE, 44 minutes in Bangui, 30 minutes in Hermanus and 45 minutes in M'Bour. Following the works of [8] and [9] these signify the total number of minutes for which GICs flowed in conductive media around the vicinity of these stations. These results are clearly summarized in Table 2. The total number of time for which │dH/dt│ > 30 nT/min in the four African stations is one minute for each of the stations. In line with the works of [8], [9] and [10] these signify the duration for which conductive media within these stations were subjected to GICs of undesirable consequences. These results are shown in Table 3.

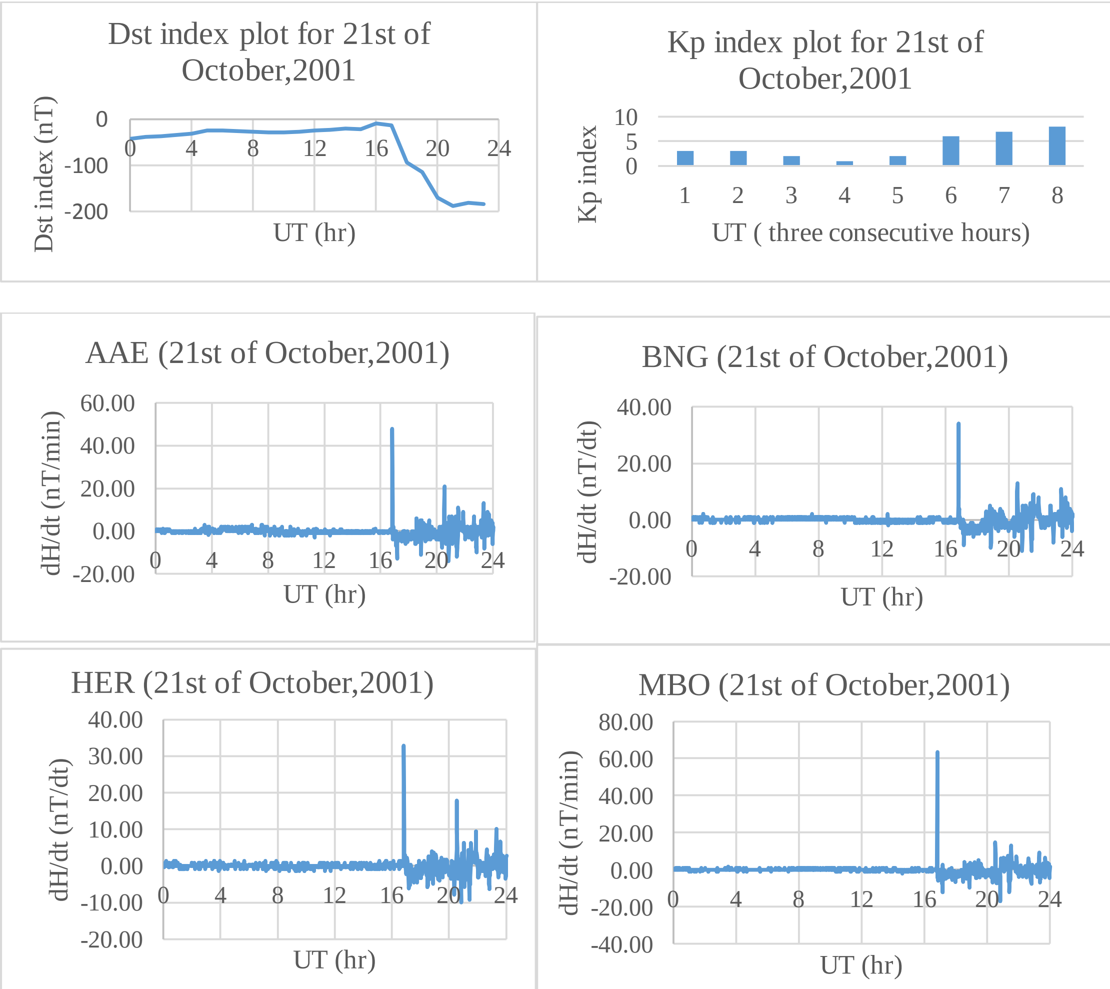


Figure 3: Graph of magnetic response for 21st of October 2001.

3.4 6th November 2001 Storm

Fig. 4 display the response plot for the storm of 6th November 2001 Storm, where a severe (very-intense) storm of minimum Dst value of -292 nT at 06:00 UT and a maximum Kp index of 8.67 respectively were observed. These results are also summarized in Table 2. The effect of this severe storm was observed by the computed values of │dH/dt│ reaching maximum values of 74.56 nT/min in Addis Ababa at 01:52 UT, 62.28 nT/min in Bangui at 01:52 UT, 69.37 nT/min in Hermanus at 01:52 UT and 62.96 nT/min in M'Bour at 01:52 UT. The total number of minutes when │dH/dt│> 5 nTmin^{-1} is 305 for AAE, 95 minutes (1 hour 35 minutes) in Bangui, 82 minutes (1 hour 22 minutes) in Hermanus and 100 minutes (1 hour 40 minutes) in M'Bour. Following [8] and [9] these signify the total time for which GICs flowed in conductive media like transformers, transmission lines etc. around the vicinity of each of these stations. These results are clearly shown in Table 2 The total number of time when │dH/dt│> 30 nT/min in Addis Ababa is 4 minutes, 1 minute each for Bangui, Hermanus and M'Bour. In line with the works of [8], [9] and [10] these signify the total number of minutes for which conductive media within these African stations were subjected to the GIC values of undesirable consequences. This is clearly shown in Table 3.

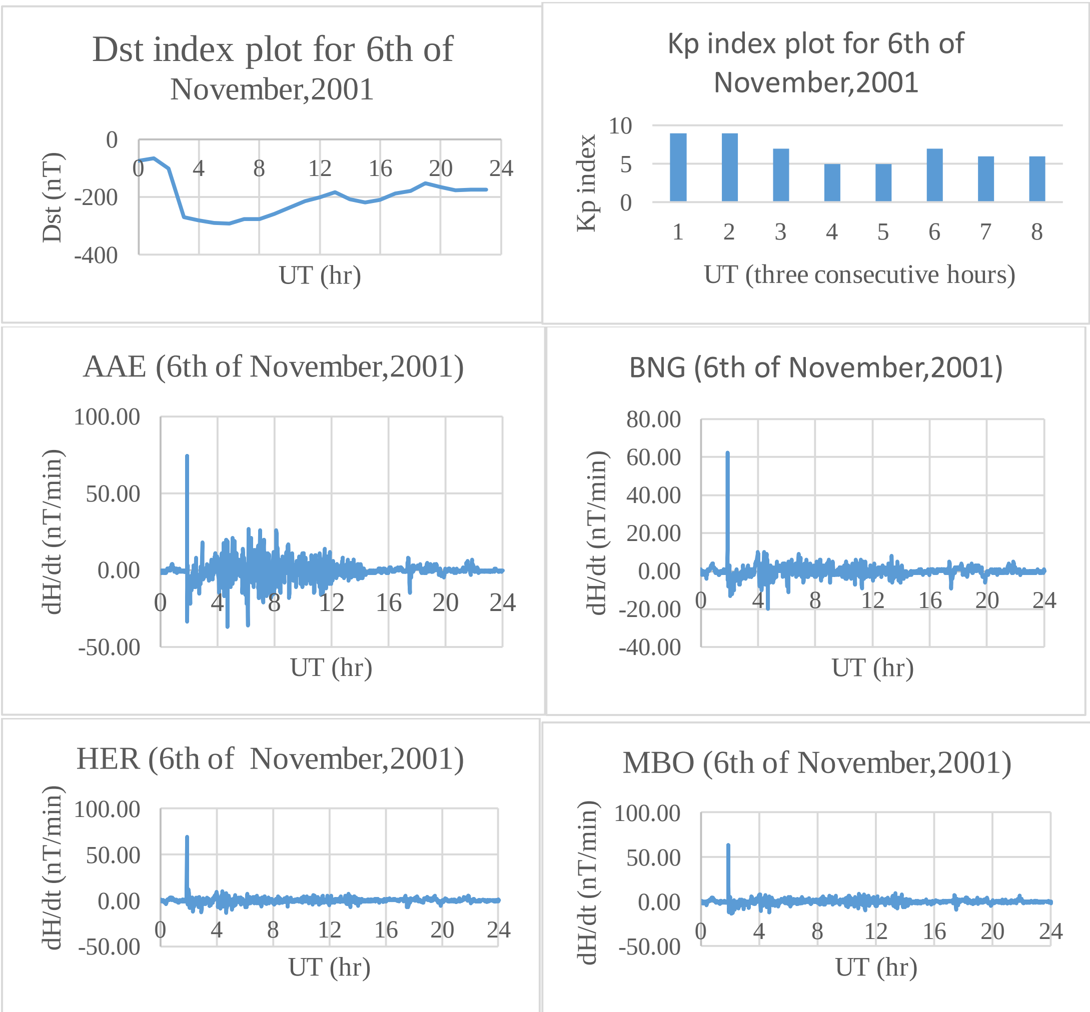
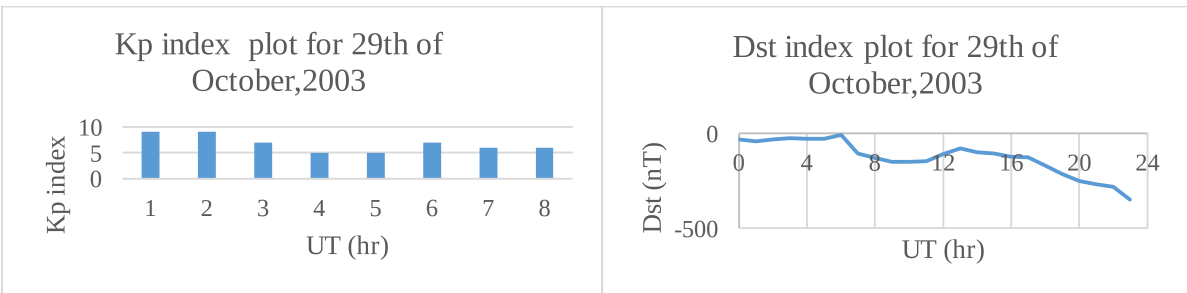


Figure 4: Plot of magnetic response for 6th of November, 2001.

3.5 29th October 2003 Storm

Fig. 5 display the response plot for the storm of 29th October 2003. A severe storm with a minimum Dst value of -350 nT was observed at 23:00 UT with the Kp index for the day reaching a maximum value of 9.00. The effect of this storm was strongly observed as the maximum values of │dH/dt│ was recorded as 172.23 nT/min at 08:56 UT in Addis Ababa (AAE), 53.17 nT/min in Bangui (BNG) at 14:24 UT, 64.23 nT/min in Hermanus at 14:24 UT and 75.04 nT/min at 14:24 UT in M'Bour. The values of dH/dt were unavailable at AAE from 16:33 to 16:42 UT, this is due to the absence of the X- and Y- component of the geomagnetic field from 16:33 to 16:42 UT. The total number of minutes when │dH/dt│> 5nTmin^{-1} is 562 in AAE, 452 in Bangui, 465 in Hermanus and 522 in M'Bour. Following the works of [8] and [9] these signify the total time GIC flowed in the conductive media around vicinity of each of these stations. The total number of time for which │dH/dt│> 30nTmin^{-1} in Addis Ababa is 72 minutes, 15 minutes for Bangui, 20 minutes for Hermanus and 40 minutes for M'Bour. In line with the works of [8], [9] and [10] these signify the total number of minutes for which conductive media around these African stations were subjected to GIC values of undesirable consequences. These results are clearly shown in Table 3.



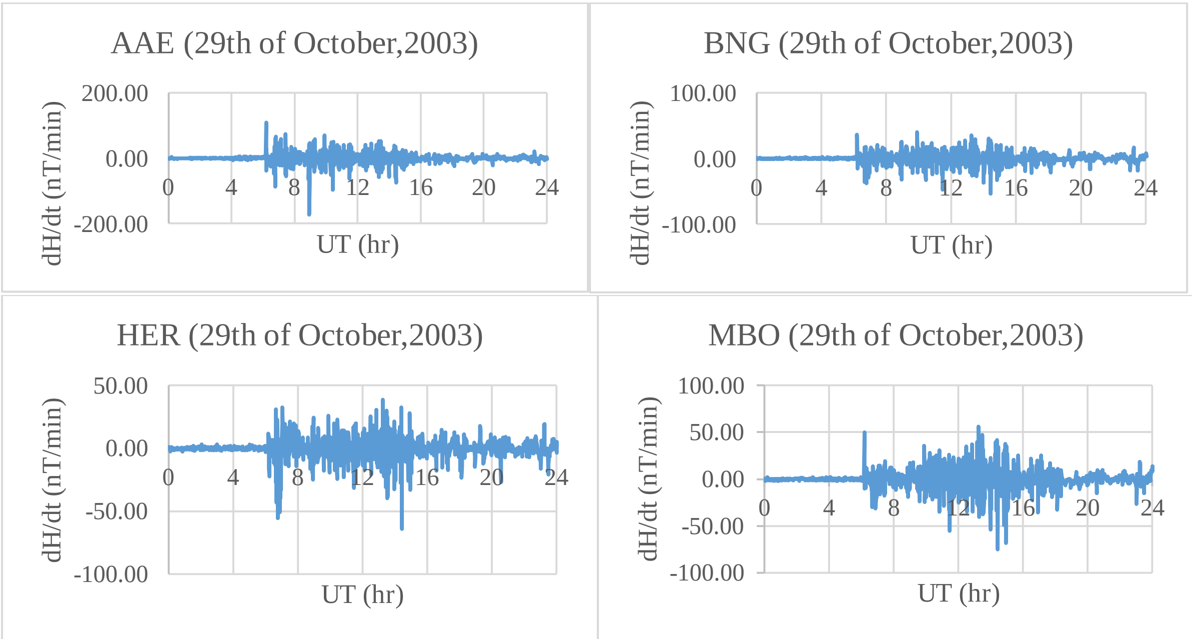
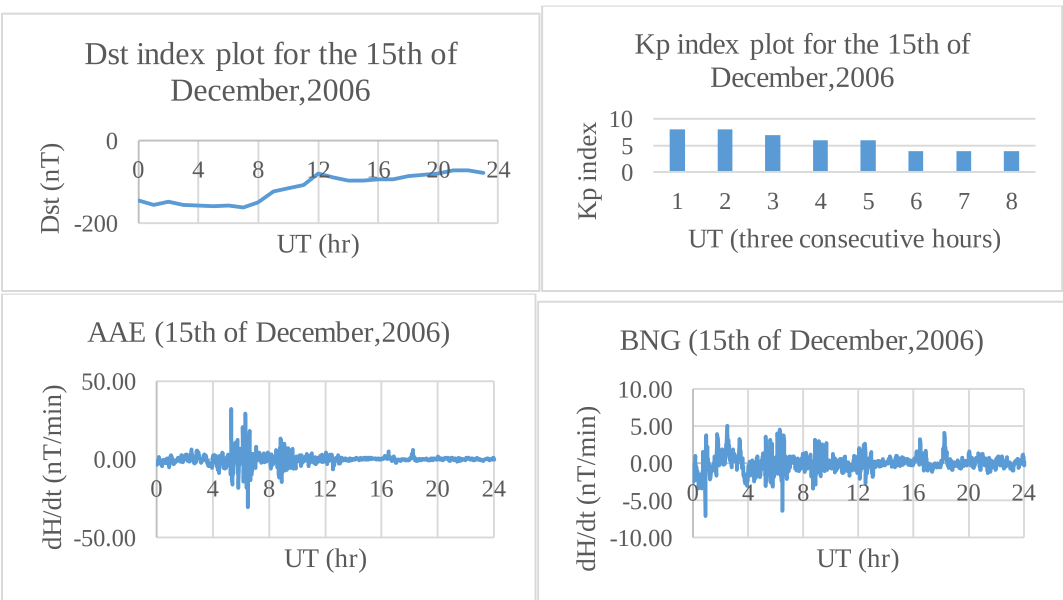


Figure 5: Plot of magnetic response for 29th of October, 2003.

3.6 15th December 2006 Storm

Fig. 6 depict the response plot for the geomagnetic storm components of Dst (nT), Kp index and dH/dt (nTmin^{-1}) on the 15th of December, 2006. An intense storm with a Dst minimum value of -162nT was observed at 07:00 UT, while the Kp index for the day reached a maximum value of 8.33. The effect of this storm was also observed by a morning-time enhancement of the time derivative of the horizontal geomagnetic field (dH/dt) between 05:00 and 07:00 UT in Addis Ababa possibly due to Equatorial Electrojet Currents and with the values of dH/dt reaching maximum values of 32.00 nT min^{-1} in Addis Ababa at 05:18 UT, 7.09 nT min^{-1} in Bangui at 00:54 UT, 10.07 nT min^{-1} in Hermanus at 00.54 UT and 8.28 nT min in M'Bour at 05:55 UT. The total number of minutes when │dH/dt│> 5 nT min^{-1} is 101 minutes in AAE, 3 minutes in Bangui, 6 minutes in Hermanus and 7 minutes in M'Bour. Following the works of [8] and [9] these signify the total number of minutes for which GICs flowed in conductive media around the vicinity of each of these stations. These results are clearly shown in Table 2. The total number of time when │dH/dt│> 30 nT min^{-1} in Addis Ababa is 2 minutes and zero (0) each for Bangui, Hermanus and M'Bour. In line with the works of [8], [9] and [10] these signify that in Addis Ababa conductive media were subjected to GIC values of undesirable consequences flowed for only two minutes and that the other three stations were not subjected to GIC values of undesirable consequence to them. These results are shown in Table 3.



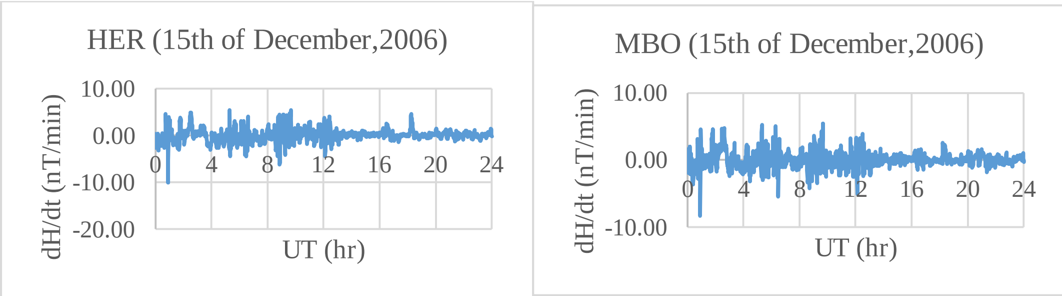


Figure 6: Magnetic response plot for 15th of December, 2006.

IV. CONCLUSION

The magnetic data obtained from four geomagnetic stations located within the African latitude namely: Addis Ababa (AAE), Bangui (BNG), M'Bour (MBO) and Hermanus (HER) during International Disturbed Days between the year 2001 and 2006 has enabled the calculation of the time derivative of the Horizontal Geomagnetic Field. From the results obtained it can be concluded that there are differences in the derivatives of the stations. These differences could be attributed to their latitudinal locations. The time derivatives were found to be more pronounced in AAE due to its closeness to the dip equator. The stations experienced the highest temporal variations of the horizontal component of the field on the 29th of October 2003, this could be as a result of the near-extreme storm of minimum Dst of -350 nT and maximum Kp index of 9.00 and least variation on 20 March 2001 possibly due to storm of minimum Dst index of -149 nT and maximum Kp index of 7.33. There is a morning-time enhancement of the time derivative of the horizontal component of the field, $\frac{dH}{dt}$ between 05:00 and 07:00 UT in Addis Ababa on the 15th of December 2006 due to Equatorial Electrojet Currents. The results (graphs) show spikes in the magnetic signatures of the stations for the six days of study which is clearly a behaviour of geomagnetically induced currents (GICs). Therefore, it can be concluded that GICs are present in conductive media around the vicinity of the four stations.

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*Corresponding Author: Madu Onyeka Emmanuel