2018 International Conference on Modeling, Simulation and Analysis (ICMSA 2018)
ISBN: 978-1-60595-544-5

Effect of Geomagnetic Induced Current in Ethiopian Power Grid

Ganebo Yared Senbato, Chun-ming LIU* and Hong-mei WANG

North China Electric Power University, Beijing China

*Corresponding author

Keywords: Geomagnetic induced current, Low latitude low voltage level power grid, Full node model, Governance evaluation.

Abstract. It is important to determine the possibility of high risk value of geomagnetic induced current (GIC), accurately define the level of power grid GIC, understand the distribution characteristics of disaster GIC, to prevent, control and evaluate the impact of magnetic storm disturbance on the power grid. Based on the full node model, the long term performance of 2003-2017 geomagnetic disturbances in Ethiopia 400kV-230kV power grid is analyzed. The results show that the probability of GIC high risk value of low voltage power grid in Ethiopia low latitude region is not zero. The GIC values in the northwest, Southeast and central regions are larger, and the GIC values in the northeast and southwest regions are smaller. When evaluating GIC, 400KV substations named S1, S2, and S8, S10, S48 and 230 kV substations such as S42, S43, S17, S16 and S53 should be monitored intensively. To ensure the calculation accuracy of high voltage power grid GIC is a prerequisite for the evaluation and governance of GIC. For GIC node accuracy, it is only need to consider the effect of 230kV grid on 400kV power system; For line GIC precision, it need to consider the influence of 230kV grid on 400kV power system and 400kV grid on 230kV power system.

Introduction

The frequency of 0.0001 ~ 0.01HZ GIC is considered to be quasi DC. This quasi DC will cause the transformer half wave saturation, which will cause [1-3] harmonic current increase, voltage drop, reactive power fluctuation and so on. Usually, high latitudes such as North America and North Europe, such as magnetic storms are strong and frequent, and GIC is harmful to the safe operation of the power grid [4-5]. With the continuous deepening of GIC research, China, Japan, New Zealand, Spain and other low and middle latitudes, [6-9] and even the equator, such as Australia, Brazil and South Africa [10-12] also suffered a lot of magnetic storm damage to power grid events. The results of literature [12] show that the highest GIC of the substation in South Africa is up to 108A during the geomagnetic storm in March 13, 1989. According to the existing research, we can know that there are many factors that influence the GIC of power grid; especially the [13-16] disturbance at low latitudes is no longer the main factor affecting the GIC size of power grid. Therefore, low latitudes, especially the GIC near the equator, cannot be ignored. Ethiopia is located between 3 degrees to 13 degrees north latitude, which belongs to a typical low latitude area and is closer to the equator. There is no accurate definition of the GIC level of the power grid in this area.

It is important to define the GIC level of Ethiopia power grid accurately and understand the distribution characteristics of disastrous GIC in the area. It is of great significance for preventing, managing and evaluating the impact of magnetic storm disturbance on the power grid. The GIC grid in various parts of the calculation and analysis only selected a geomagnetic disturbance events, such as the from November 9, 2004 to 10 during the storm events, the establishment of GIC model; on July 14, 2012 to 15 during the grid GIC measured value and calculated value were analyzed; was established in 2003 Halloween during the magnetic storm risk assessment model of GIC power grid in Spain, look for weak links to geomagnetic storm disturbance in the grid. But through the results of the study we can find that the study of minority cases unable to fully understand the occurrence and harm level of GIC, is also a part of the literature on long-term observation of magnetic storm data grid GIC evaluation analysis through comparative analysis of strong storms and faults appear a large number of historical data the time node, long-term performance simulation grid GIC; selected three historical storm events, calculating the grid GIC and get different Kp index in the range of GIC. Based on geomagnetic index Dst, we selected 2003-2017 years of all Mega storms and some large magnetic storm events for 11 times. We simulated the long-term performance of magnetic storm disturbance in Ethiopia 400-230kV power grid, and analyzed the GIC data, and gave the spatial distribution characteristics. The value is pointed out. In addition, the November 2004 magnetic storm event with the longest duration in the 11 geomagnetic storm event is calculated in detail, and the results of the two calculations are compared.

Calculation of GIC in Power Grid

GIC calculations can be divided into two steps: 1) Calculation of induced geoelectric field based on geomagnetic storm data; 2) GIC calculation based on full node model of actual power grid.

The Calculation of Induced Geoelectric Field

Considering the actual electric structure of the earth, a one-dimensional layered earth conductivity model is used to calculate the induced geoelectric field by using the data of geomagnetic storms measured by the actual geomagnetic observatory. The relation between the induced geoelectric field and the magnetic field in the frequency domain is:

$$\dot{E}_x = \frac{1}{\mu_0}\dot{B}_y Z_0 . \tag{1}$$

$$\dot{E}_y = -\frac{1}{\mu_0} B_x Z_0 . \tag{2}$$

Among them, $\dot{E}_x$, $\dot{E}_y$ is the north-south and east-west components of induced geoelectric field; $\dot{B}_x$, $\dot{B}_y$ is the north-south and east-west components of geomagnetic field.

Since the given data are the time series of the magnetic component, when calculating the induced geoelectric field, the magnetic field component in the time domain is transformed into the frequency domain by FFT transform. By using the formula (1) and (2) calculating the electric field component, the time series of the induced geoelectric field component can be obtained by the FFT transform.

Full Node GIC Computing Model

When the transformer substation adopts the autotransformer, there is a direct electrical connection between the primary side and the auxiliary side of the transformer. When calculating the power grid GIC, the transformer auxiliary grid cannot be ignored. In this paper, a full node GIC model based on node admittance matrix method is proposed by using literature [6] to calculate GIC in dual voltage level power grid. The calculation circuit of GIC node admittance is shown in Figure 1.

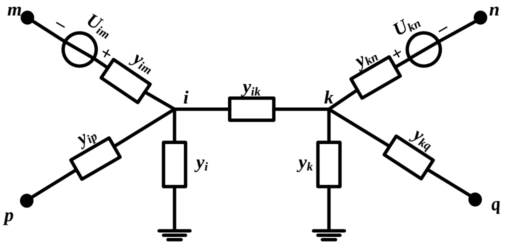

Figure 1. The calculation circuit of GIC node admittance.

For any ground node *i*, the relationship between the ground node current i_i and the ground node voltage u_i is:

$$i_i = u_i y_i . \quad (3)$$

The solution formula of node voltage in matrix form is:

$$V = Y^{-1} J . \quad (4)$$

For any transmission line with arbitrary ends *k* or *i*, the calculation formula of the line current i_{ki} is:

$$i_{ki} = \left(U_{ki} + \left(u_k - u_i\right)\right) y_{ki} . \quad (5)$$

Line induced voltage U_{ki} is:

$$U_{ki} = E_x L_x + E_y L_y . \quad (6)$$

Original Data

Geomagnetic Storm and Earth Electrical Structure Data

The two geomagnetic indices respectively used to describe the intensity of geomagnetic storms in the world are Kp index and Dst index. The Dst index is measured every hour, it mainly measures the intensity change of geomagnetic horizontal component. The site (http://isgi.unistra.fr) records the monitoring data of the Addis Ababa Geomagnetic Observatory (AAE) over a long time scale. According to the Dst data provided by the website, we selected all giant storms (Dst≤-200) and part of the big storm events (-200<Dst≤100) in 2003-2017, a total of 11 times, as shown in Table 1.

Table 1. Geomagnetic storm events in 2003-2017.

	DATE	Dst_MIN		DATE	Dst_MIN
1	2003-10-29	-350	5	2006-12-15	-162
	2003-10-30	-383	6	2011-10-25	-147
	2003-10-31	-307	7	2012-03-09	-145
2	2003-11-20	-422	8	2012-07-15	-139
	2003-11-21	-309		2012-07-16	-113
3	2004-11-08	-374	9	2013-03-17	-132
	2004-11-09	-214	10	2015-03-17	-222
	2004-11-10	-263		2015-03-18	-214
	2004-11-11	-106	11	2015-12-20	-155
4	2005-05-15	-247		2015-12-21	-148
	2005-05-16	-101			

Table 2. Earth resistivity in Ethiopia area.

One-dimensional layered earth resistivity model					
Earth resistivity	0.02	0.00002	0.005	0.01	0.001
Depth	0.1	8	31	100	∞

Power Grid in Ethiopia Area

Ethiopia is located near the equator, belongs to the low latitude country, the geomagnetic storm intensity is relatively small, but because the power grid GIC is not only related to the geomagnetic storm intensity, the earth electrical structure and the actual power grid parameters will affect the magnitude of the GIC. According to the existing research, geomagnetic storms in low and middle latitudes are no longer the main factors affecting GIC size of power grid. Therefore, it is practical significance to calculate the GIC in the low latitude area such as Ethiopia, and then assess the risk of geomagnetic storm disaster and control the power grid GIC.

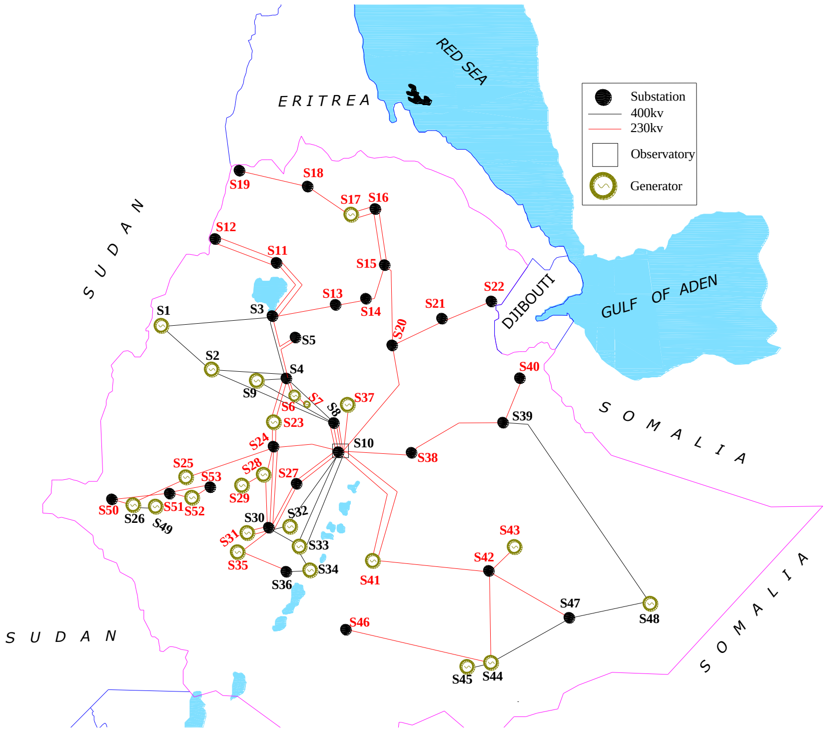

Figure 2. Geographical wiring diagram of dual voltage Ethiopia power grid.

In this paper, the full node model of 400KV and 230KV dual voltage grid is built. Fig. 2 is a geographic wiring diagram of a dual voltage network of Ethiopian power grid, consisting of 19 sets of 400KV and 34 sets of 230KV transformers, 19 transmission lines with 400KV and 47 with 230KV.The full node model of double voltage network requires 3 parameters: transformer parameter (DC resistance value of transformer windings), line parameter (line length and DC resistance value per unit length) and substation parameters (geographic coordinates and grounding resistance value of substation).

GIC Results Analysis

In this paper full node model method is used to calculate the node GIC (single phase value) generated by the 11 magnetic storm events selected by Table 1 in the power grid. The results are obtained through statistical analysis of the sample data.

At the time scale, the number of GIC node samples for each site includes 2.9848*10^^{4}. Take one of the sites as an example Sululta substation (S8), GIC of low voltage grid in low latitude area has small probability of large numerical case: the maximum node GIC is 284.75A, defined as low probability of extreme value, symbol for GICMax-L, the probability is only 0.003%; the minimum value is 0.000291A, the node GIC is between 0.000291A and 28A. Its cumulative probability has reached 96.49%, it equals to the probability that the node GIC is greater than 28A was 3.51%. 28A was defined as the high probability of extreme value, symbol for GICMax-H; the average value was 6.5912A. The average GIC power grid is greatly affected by the maximum probability and at the same time, the probability of maximum GIC occurrence is very low. Therefore, the average value of GIC is no longer discussed in this paper.

Conclusion

In this paper, based on the full node modeling method of multi voltage level, taking 400kV-230kV power grid in Ethiopia as an example, the low voltage power grid GIC in low latitude area is calculated and analyzed. The main conclusions are as follows:

1) The power grid GIC generated by 11 geomagnetic storms in 2003-2017 years is analyzed statistically. Ethiopia is located in the low latitude area, the possibility of high risk value of

400kV-230kV power grid GIC exists, and the extreme value of GIC of the low probability grid generated by 89% substations exceeds 20A, and the maximum value is 342.4A. Only reference to the high probability GIC extreme value, the range of value is [0.67A, 34A], the harm caused by the grid still need to be paid attention to. Most of the high probability extremes appear in the northwest of Ethiopia, the southeast region and the central part of the capital; the GIC of the grid caused by geomagnetic storms in the northeast and southwest regions is smaller. In the hazard management and risk assessment of power grid GIC, the long term performance of geomagnetic disturbance in the power grid should be taken into account. Two parameters, namely, high probability extreme value and low probability extreme value, should be integrated to formulate a relatively reasonable governance scheme and evaluation system.

2) The third longest geomagnetic storm events in 11 magnetic storm events are analyzed in detail. Although the power grid GIC is affected by many factors, it has the largest correlation with the East and West components of the induced geoelectric field. Overall, the level of GIC in 400kV power grid is higher than that of 230kV, but there are still 230kV substations and lines with higher GIC value. With the conclusion of the 11 geomagnetic storm events, in the formulation of power grid GIC governance program evaluation system, we should focus on monitoring 400 kV substations S1, S2, S8, S10, S48, and 230 kV substations S42, S43, S17, S16, S53 and other locations of power grid GIC.

3) On the basis of GIC calculation of dual voltage network in the third storm event, the 400kV and 230kV single voltage grid GIC are calculated respectively. The interaction between the grid GIC of the two voltage grids is discussed and analyzed. Increasing the 230KV system has a greater impact on the 400KV system, and the impact on the line GIC is greater than the impact of node GIC; the increase of 400KV power grid has a great influence on the GIC of 230KV power grid, and has little influence on its node GIC. Considering the influence of 230kV power grid on 400kV power grid GIC, the calculation accuracy of GIC of high voltage power grid is the precondition of defending geomagnetic disturbance, formulating reasonable management scheme and correct risk assessment. A figure in your paper should be like the next one.

Acknowledgement

This research financially supported by the China scholarship council and Ethiopian ministry of education.

References

[1] Albertson V D, Thorson J M, Miske S A. The Effects of Geomagnetic Storms on Electrical Power Systems [J]. IEEE Transactions on Power Apparatus & Systems, 1974, PAS-93(4):1031-1044.

[2] Molinski T S. Why utilities respect geomagnetically induced currents [J]. Journal of Atmospheric and Solar-Terrestrial Physics, 2002, 64(16):1765-1778.

[3] Liu Lianguang, Liu Chunming, Zhang Bing. Effects of geomagnetic storm on UHV power grids in china [J]. Power System Technology, 2009, 33(11):1-5.

[4] Kappenman J G. Geomagnetic Storms and Their Impact on Power Systems [J]. 1996, 16(5):5.

[5] Wik M, Viljanen A, Pirjola R, et al. Calculation of geomagnetically induced currents in the 400 kV power grids in southern Sweden [J]. Space Weather-the International Journal of Research & Applications, 2016, 6(7):1-11.

[6] Liu C M, Li Y L, Chen L. Modelling geomagnetically induced currents in Xinjiang 750kV power grid in China[J]. 2013:1-5.

[7] Pulkkinen A, Kataoka R, Watari S, et al. Modeling geomagnetically induced currents in Hokkaido, Japan [J]. Advances in Space Research, 2010, 46(9):1087-1093.

[8] Béland J, Small K. Space Weather Effects on Power Transmission Systems: The Cases of Hydro-Québec and Transpower New ZealandLtd [M]// Effects of Space Weather on Technology Infrastructure. Springer Netherlands, 2004:287-299.

[9] Torta J M, Marsal S, Quintana M. Assessing the hazard from geomagnetically induced currents to the entire high-voltage power network in Spain[J]. Earth Planets & Space, 2014, 66(1):1-17.

[10] Marshall R A, Gorniak H, Walt T V D, et al. Observations of geomagnetically induced currents in the Australian power network [J]. Space Weather-the International Journal of Research & Applications, 2013, 11(1):6-16.

[11] Barbosa C D S, Hartmann G A, Pinheiro K J. Numerical modeling of geomagnetically induced currents in a Brazilian transmission line [J]. Advances in Space Research, 2015, 55(4):1168-1179.

[12] Koen J, Gaunt T. geomagnetically induced currents in the Southern African electricity transmission network[C]// Power Tech Conference Proceedings, 2003 IEEE Bologna. IEEE, 2003:7 pp. Vol.1.

[13] Albertson V D, Thorson J M, Miske S A. The Effects of Geomagnetic Storms on Electrical Power Systems [J]. IEEE Transactions on Power Apparatus & Systems, 1974, PAS-93(4):1031-1044.

[14] Kappenman J G. Storm sudden commencement events and the associated geomagnetically induced current risks to ground-based systems at low-latitude and midlatitude locations [J]. Space Weather-the International Journal of Research & Applications, 2016, 1(3):1-16.

[15] Radasky W A, Kappenman J G. Impacts of geomagnetic storms on EHV and UHV power grids[C]// Electromagnetic Compatibility. IEEE, 2010:695 - 698.

[16] Zheng K, Boteler D, Pirjola R J, et al. Effects of System Characteristics on Geomagnetically Induced Currents[J]. IEEE Transactions on Power Delivery, 2014, 29(2):890-898.