OBSERVATION AND MODELING OF GIC IN THE CHINESE LARGE-SCALE HIGH-VOLTAGE POWER NETWORKS

Chunming. Liu and Yunlong Li
School of Electrical and Electronic Engineering, North China Electric Power University[1]

Keywords

Geomagnetic induced currents (GIC), Geomagnetic Storm, Mid-low latitude, Power grid

Abstract

During geomagnetic storms, the geomagnetically induced currents (GIC) cause bias fluxes in transformers, resulting in half-cycle saturation. Severely distorted exciting currents which contain enormous amounts of harmonics threaten the safe operation of other equipment and even the whole power system. This paper compares current data measured in transformer neutrals and magnetic recordings, and proves that the GIC amplitude can also be quite large even in mid-low latitude areas. The GIC in the Chinese Northwest 750kV Power Grid under effect of geomagnetic storm are modeled based on the Local Plane Wave Method. The results show that GIC flowing in some of transformers exceed allowable threshold value during strong geomagnetic storms. The GIC are not only a high-latitude problem but networks in middle and low latitudes can be impacted as well, which needs attention from relevant departments.

Introduction

During strong space weather storms which are caused by the activity of the Sun, the Earth's magnetic field is intensely disturbed by the Space Current System in the Magnetosphere and Ionosphere. The electric field induced by time variation of geomagnetic in the Earth can drive geomagnetically induced currents (GIC) through the loop consisted by transmission lines, neutral grounded transformers and the Earth. The frequency of GIC is 0.0001-0.01Hz. The quasi-DC cause bias fluxes in transformers which resulting in half-cycle saturation due to the nonlinear of core material [1, 2]. The sharply increased magnetize current with serious waveform distortion lead to temperature and vibration rise in transformers, reactive power fluctuations, voltage sag, relaying protection mal-operation and possibly even a collapse of the whole power grid [3].

Large GIC are usually considered to happen at high latitude such as North America and Nordic, where tripping accidents and even blackouts due to GIC happened in power grid [3，4]. Although China is located in mid-low latitude, large currents at transformer neutral point have been monitored when geomagnetic storms occurred, meanwhile transformers had abnormal noise and vibration many times. Those events were proved to be caused by GIC through analysis of the magnetic storm data and the current monitored from transformer natural point, [5, 6]. The power grid is becoming higher voltage, longer distance and larger capacity with the developing of economy in China. So, the risk which power grid will suffer may increase. Northwest 750kV power grid in China has longer transmission distance and

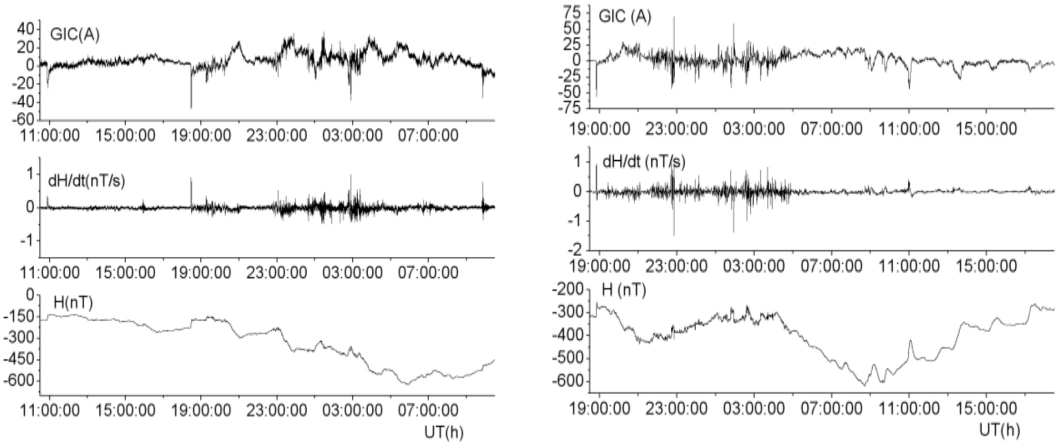
[1] 2 Beinong Road, Changping District, Beijing 102206, China

less line resistance, may suffer large GIC during strong geomagnetic storm. Thus it is important to model the GIC in power networks in this region.

GIC Observation in Chinese High Voltage Power grid

We acquired the data of currents through neutral point of transformer at Ling'ao nuclear power plant (22.6° N, 114.6° E) in the Guangdong Province. Besides, the geomagnetic field data of Zhaoqing Geomagnetic Observatory (23.1° N, 112.3° E) had been collected. Figure 1 show the neutral point current (top panel), the geomagnetic field data (bottom panel), and the variation rate of the geomagnetic field (middle panel) during magnetic storms on 7-8 (a) and 9-10 (b) November 2004. The occurrence time of the current peak matches with that of the geomagnetic field variation rate. It is confirmed that there is no HVDC (high voltage direct current) monopole operation during that time. So it reasonable to believe that the currents were GIC induced by geomagnetic storms. The maximum value of GIC is up to 75.5A, which is higher than that caused by the monopole operation of HVDC.

Figure1: GIC monitoring data of the Ling'ao nuclear power plant on 7-8 (a) and 9-10 (b) November 2004



(a) (b)

Method of Modeling GIC in Power Grid

The modeling of GIC in power grid can be divided into two steps [7]: step 1, calculating the geoelectric field induced by magnetic storm; step 2, calculating the GIC in power grid. The effect of induced electric field is equivalent to voltage source in power grid, which can convert the GIC calculation into a circuit problem in step 2.

A. Calculating induced Electric Field in a Layered Earth Model

Set up the three-dimensional coordinate system, the x and y direction are chosen to be north and east, the z axis points downwards. According to the Plane Wave Method [8], the relation between geoelectric field *E* and geomagnetic field *B* can be expressed as equation (1) and (2).

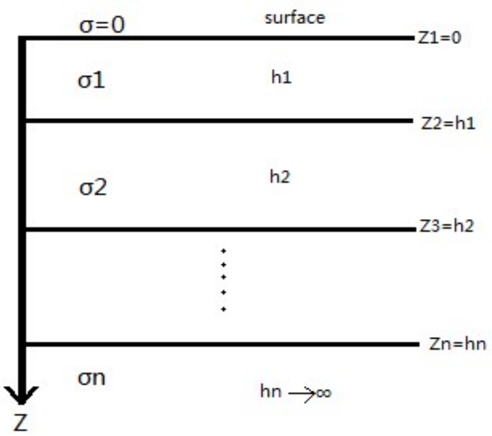
$$\dot{E}_x = \frac{1}{\mu_0}\dot{B}_y Z \qquad (1)$$

$$\dot{E}_y = -\frac{1}{\mu_0}\dot{B}_x Z \qquad (2)$$

Where μ_0 is the vacuum permeability and *Z* is surface impedance of the earth which depends on the conductivity of the earth and angular frequency ω.

Compared with the uniform earth model, the one-dimensional layered earth model are more accurate and reasonable. Figure2 shows a layered earth model that contain n layers, the conductivity of each layer are σ_1, σ_2, … , σ_n and the thickness of each layer are h_1, h_2, …, $h_n \to \infty$.

Figure2. Layer Earth Model of Conductivity



The thickness of the bottom layer is $h_n \to \infty$, and there exist $E_x = 0$ and $B_y = 0$ when $z \to \infty$, hence the wave impedance of the nth layer is (3).

$$Z_n = \mu_0 \frac{\dot{E}_x}{\dot{B}_y} = \frac{j\omega\mu_0}{k_n} = \sqrt{\frac{j\omega\mu_0}{\sigma_n}} \tag{3}$$

The wave impedance within the mth layer can be expressed as equation (4),

$$Z_m = Z_{0m} \frac{1 - L_{m+1} e^{-2k_m h_m}}{1 + L_{m+1} e^{-2k_m h_m}} \tag{4}$$

if we define

$$Z_{0m} = \frac{j\omega\mu_0}{k_m}$$

and

$$L_{m+1} = \frac{Z_{0m} - Z_{m+1}}{Z_{0m} + Z_{m+1}}.$$

In the model, the bottom of mth layer is the top of (m+1)th layer, therefore equation (4) can be seen as a recursive formula of wave impedance, though which we can calculate the surface impedance of the earth Z. Then the geoelectric field can be calculated according to equation (1) and (2).

B. Modeling of GIC in Power Grid

The frequency of GIC in power grid is very low, thus the GIC can be treated as direct-current. The effect of ground induced electric field on power grid is equivalent to a set of voltage sources between different grounding points. The value of the voltage is the integral of the electric field along the line.

$$V_{AB} = \int_A^B \bar{E} \cdot d\bar{l} \tag{5}$$

If the electric fields are uniform, the integrals are independent on the path. Therefore equation (5) can be simplified to equation (6).

$$V_{AB} = L_{AB}(E_x \sin\theta + E_y \cos\theta) \tag{6}$$

Where, L_{AB} is the direct distance between nodes A and B; θ is the angle between the line from A to B and y axis.

The GIC in the power grid can be expressed as equation (7) [9].

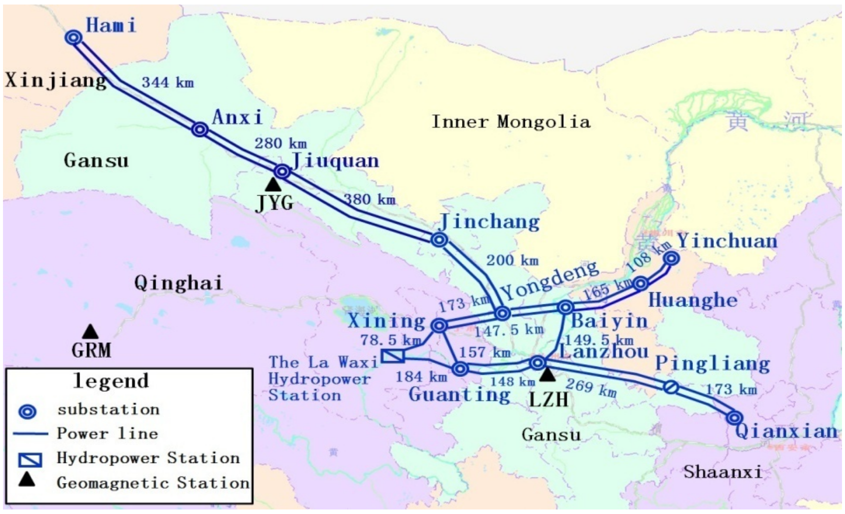
$$\mathbf{I} = (\mathbf{1} + \mathbf{YZ})^{-1}\mathbf{J} \tag{7}$$

Where, Y is the admittance matrix and J is the grounded GIC in the condition of ideal ground that is the grounding resistance is zero.

Modeling GIC in Chinese Northwest 750kV power grid

The problem of GIC is more serious in Northwest 750kV because of the higher voltage and the lower earth conductivity. The power grid (shown Figure 3) in which GIC calculation is made in this paper mainly locates in Gansu province. We ignored lower voltage part of the power grid when modelingf GIC, because the resistences of that part are much larger and it is considered to have little influence on GIC flowing in the 750kV part.

Figure3. Northwest 750kV Power Grid



A. The Geoelectric field calculation

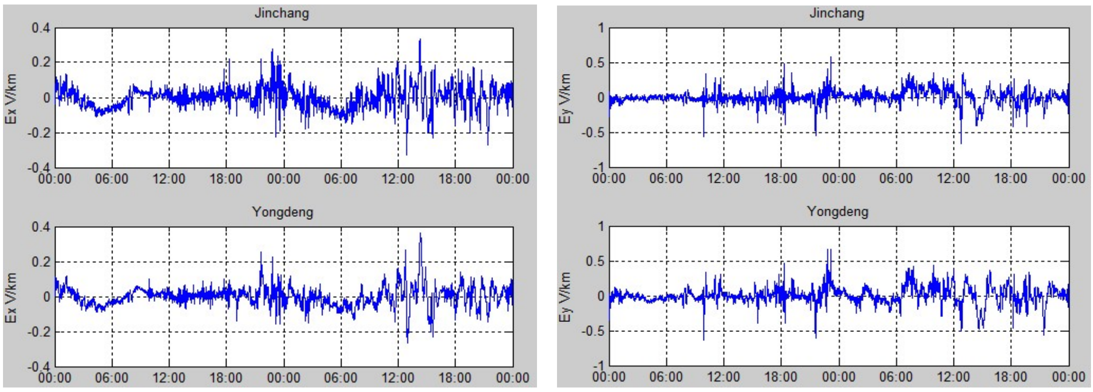
The data of geomagnetic storm in this paper is 29-30 May 2005. The power grid locates in a large region where geomagnetic components cannot be considered to be same everywhere. The magnetic data from four geomagnetic observatories, whose locations are shown in Table 1, are used to calculate geoelectric field during the magnetic storm. The local magnetic data are interpolated by using the spherical elementary current systems (SECS) method [10].

Table1. Locations of Geomagnetic Observatories

Name	Longitude(°E)	Latitude(°N)
WMQ	87.7	43.8
GRM	94.9	36.4
LZH	103.8	36.1
JYG	98.2	39.8

The earth conductivities are quite different at each location, so that the geoelectic fields are calculated segment by segment according to its local magnetic data and local layered earth model. Figure 4 shows the geoelectric field in Jinchang and Yongdeng. It is known from the calculation results that the largest Ex is 0.36V/km and Ey is 0.668V/km.

Figure4. Calculation results of Geoelectric field

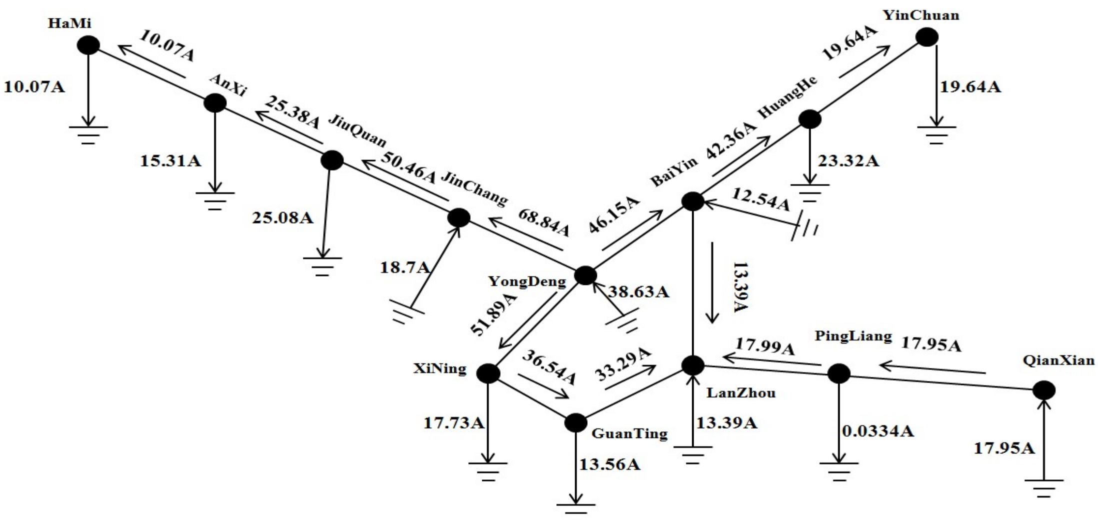


(a) Ex – T (b) Ey - T

B. GIC calculation in Northwest 750kV Power Grid

The GIC through neutral points of transformers and transmission lines have been calculated. Figure 5 shows the peak GIC in power grid of every node and line. It can be seen that the largest GIC through neutral point is 38.63A/phase which locates in Yongdeng station, and the peak GIC through transmission line is 68.84A/phase which is in the line from Yongdeng to Jinchang. The total GIC through neutral point at Yongdeng will exceed 100A in three phases, which can cause harmful effect on transformer and power system when strong magnetic storm happens.

Figure5 Calculated Peak GIC in Northwest China 750kV Power Grid



Conclusions

The power grid in China also suffered large GIC during geomagnetic storm according to the monitored current through neutral point at Ling'ao Nuclear Power Plant during strong magnetic storms. The GIC in the Chinese Northwest 750kV power grid during a specified magnetic storm have been modeled based on the Local Plane Wave Method. It can be seen from the result that some nodes are sensitive to geomagnetic storms and the value of GIC can be large enough to cause harmful effect on transformers and power system during strong geomagnetic storms. The GIC are not only a high-latitude problem but networks in middle and low latitudes can be impacted as well. Factors increasing GIC risks in China include the very large size, small resistances of the transmission lines, and high resistivity of the earth.

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Biographies

Chunming Liu received MSE and PhD degrees in Electrical Engineering in 2000 and 2009, respectively, from North China Electric Power University, China. His work focused on geomagnetically induced currents in the power grid, including: monitoring, modeling, and assessing the influence on security of power system. Currently he is an Associate Professor in North China Electric Power University. He is in charge of a research project on modeling GIC in power grid supported by Nature Science Foundation of China (NSFC) and playing a big role in an international cooperation research project on GIC supported by Chinese Ministry of Science and Technology. He received one of the Chinese Work Safety Science and Technology Progress Award in 2011, and one of the Chinese Power Science and Technology Progress Award in 2010. He won one of the Outstanding Doctoral Thesis of Beijing in 2009. He is also a Senior Engineer in Electrical Engineering since 2003.