Calculation of induced geoelectric field distribution in wide area geomagnetic storms based on time harmonic fitting

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Abstract. Ate magnetic field that changes during the magnetic storm will produce the geomagnetic ally induced current (GIC), which will threaten the safe operation of the power grid. It is very important to accurately calculate the effect of GIC on the effect of magnetic storm on the power grid. In order to discuss the actual influence of magnetic storm on the power grid, the sinusoidal function is synthesized by the harmonic fitting method, which is equivalent to the maximum variation rate of the geomagnetic field in the time domain. The amplitude and frequency of the sinusoidal function are selected to calculate the frequency in the frequency domain, so that the calculation is more convenient and rapid. And select the typical magnetic storm of November 7-9, 2004, take the one dimensional stratified earth resistivity model as an example, use the finite element method to calculate the intensity distribution of the wide area electric field, and find that the North China and Southern China region are more seriously affected by the magnetic storm.

1. Introduction

When the solar surface is active, the geomagnetic field is strongly disturbed by the magnetospheric-ionospheric space current system. At this time, the earth's magnetic field can be monitored on the global surface. This phenomenon is called "magnetic storm" [1].

Geomagnetic induced current (GIC) is generated in a circuit composed of transmission lines, neutral grounded transformers and the earth. GIC frequency is 0.01-0.0001 Hz. This quasi-direct current poses a serious threat to the safe operation of power grid and its equipment, including maloperation of relay protection devices, capacitor banks. And static var compensator overload, generator local overheating and mechanical vibration, HVDC converter terminal AC side filter overload, system voltage fluctuations, etc. [2]. Before 2000, China's power grid was smaller and the transmission line was short. The impact of GIC was not obvious. However, with the implementation of the strategy of power transmission from west to East and the nationwide interconnection, the power grid has suffered many times from the greater GIC intrusion [3, 4].For example, in the strong magnetic storm on November 10, 2004, the GIC amplitude recorded at Ling'ao Nuclear Power Station was as high as 75.5 A, which was enough to arouse attention [5, 6]. Compared with 500 kV grid, 750 kV EHV and 1000 kV EHV grid have smaller unit resistance and longer transmission distance, so it is easy to produce larger GIC. Therefore, it is very important to accurately calculate the degree of influence of magnetic storms on China's power grid.

The GIC level is related to many factors, such as the intensity of geomagnetic field change, grid structure, geographic latitude, geoelectric structure and so on. It is known from reference [7] that there is a strong correlation between GIC and the rate of variation of the horizontal component of the geomagnetic field with time (dH/dt). Therefore, on the basis of reference [7], a large dH/dt pulse in 2004 is selected to calculate the national electric field intensity level. But the time-varying magnetic field is caused by the magnetic storm. In order to simplify the calculation, a time-harmonic fitting method is proposed to fit the larger pulse interval of dH / dt into a sinusoidal function for frequency domain calculation. The algorithm is verified by Taking Northwest Laxiwa area as an example. Finite element method and one-dimensional horizontal stratified conductivity model are used to calculate and analyze the distribution of electric field intensity in China under typical magnetic storms, which lays a foundation for accurately calculating the impact of GIC on power grid.

2. Verification of time harmonic fitting algorithm

China's geomagnetic network currently has 15 stations and 22 stations of two types. At present, the magnetic storm data can be collected in minutes and seconds of three components of the geomagnetic field (that is, the total geomagnetic field strength F, magnetic declination D and geomagnetic field horizontal component H) data. This paper uses second's level H and D data.

In order to analyze the national electric field intensity level directly and quickly, this paper adopts the one-dimensional horizontal stratified earth conductivity model shown in Fig. 1. The model only considers the variation of earth resistivity with depth, so it is typical to choose one-dimensional stratified structure as the physical model of earth conductivity. Because of the skin effect of the time-harmonic electromagnetic field propagating in a uniform earth conductor, the penetration depth delta is used to characterize the depth of the electromagnetic field attenuating to 0.368 when it propagates underground. After a distance of 5-6 penetration depths, the attenuation of the electromagnetic field to less than 1% of the ground value can be considered to be approximately zero.

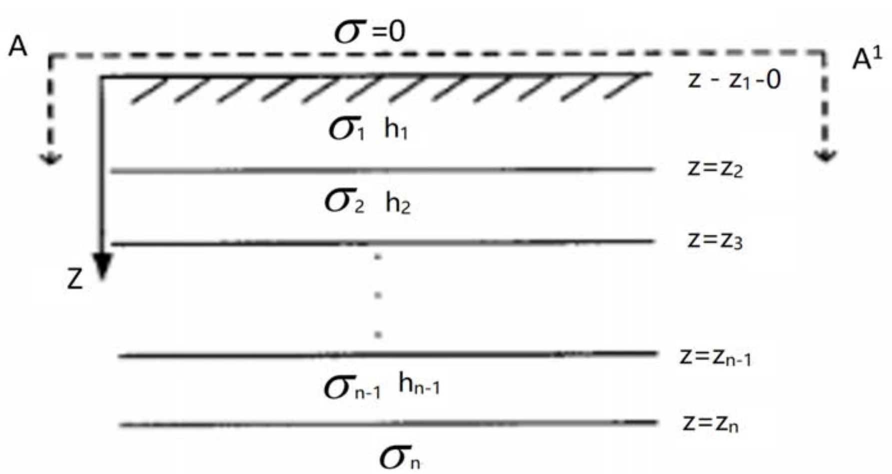

Figure 1. One dimensional stratified geodetic conductivity model [6, 7]

Because one-dimensional stratified geoconductivity model does not consider the change of horizontal conductivity, it takes the horizontal direction of the earth, the range is 200 km *200 km, the depth is 500 km [8]. According to the geomagnetic coordinate system, the X axis is geomagnetic northward, the Y axis is geomagnetic eastward, and the Z axis is depth. In this model, the vector magnetic potential in two-dimensional field meets the Kulun specification automatically:

$$-\frac{1}{\mu_0}\nabla^2 \dot{A}_y + j\omega\sigma\dot{A}_y = \dot{J}_{sy} \tag{1}$$

At the interface of different conductor structures, the joining conditions are:

$$\dot{A}_{y2} = \dot{A}_{y1} \tag{2}$$

Due to the attenuation of the electromagnetic field by the earth conductor, the boundary conditions of the field of the earth conductor satisfy:

$$A_y = 0 \tag{3}$$

The boundary conditions of the air region are:

$$\frac{1}{\mu_0}\frac{\partial \dot{A}_y}{\partial n} = 0 \tag{4}$$

GIC is produced by the induction of electric field by time-varying magnetic field, so it is a time-domain problem to solve the electric field strength. In order to accurately analyze the impact of geomagnetic storms on the national power grid, a time-harmonic fitting method is proposed. The time domain problem of magnetic storms is transformed into the frequency domain problem by means of the Richter transform. Take the northwest Laxiwa area as an example to verify the resistivity data as shown in Table 2. The geomagnetic storm data are selected from Kashi geomagnetic station which is close to the latitude. From the data of electromagnetic field variation recorded by Kashi geomagnetic station on November 7, 2004, the data of 10:51:40-10:54:00 are selected for verification.

First, the original data of the geomagnetic station are processed to get the change amount. According to formula (1), we can get geomagnetic field variation Bx in the East and West and by in the north-south direction. Select the interval between the delta Bx and the maximum variation of delta by, as shown in Figure 2. Sine fitting is done with MATLAB, and the fitting result is shown in Figure 3. The expressions of delta Bx and delta by are obtained through time harmonic fitting.

$$f_x(t) = 12.68 - 15.54\cos 0.03469t + 11.611\sin 0.03469t = 12.68 - 19.4\cos(0.03469t + 0.8) \tag{5}$$

$$f_y(t) = -19.16 + 21.09\cos 0.06526t - 7.074\sin 0.06526t = -19.16 + 22.24\cos(0.06526t + 0.4) \tag{6}$$

Table 1. The conductivity of the Lexica region [8, 9]

depth/km	Conductivity/($S \cdot m^{-1}$)
0-41	0.00014
41-45	0.106
45-124	0.0005
124-140	0.0476
140-156	0.00119
156-500	0.02

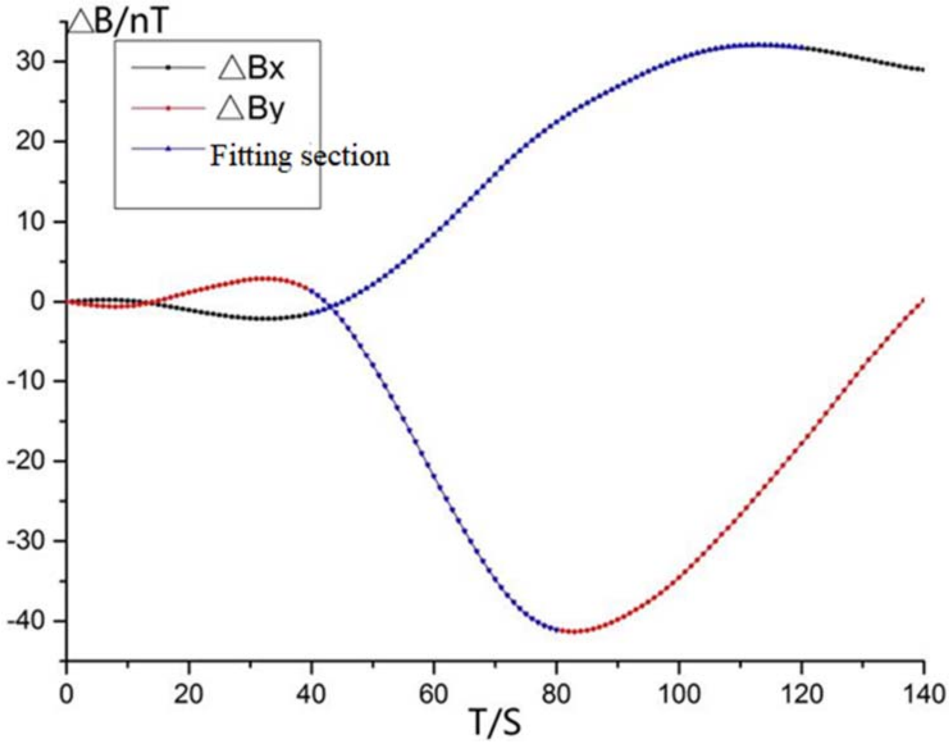

Figure 2. △Bx and △By graphs and fitting segments

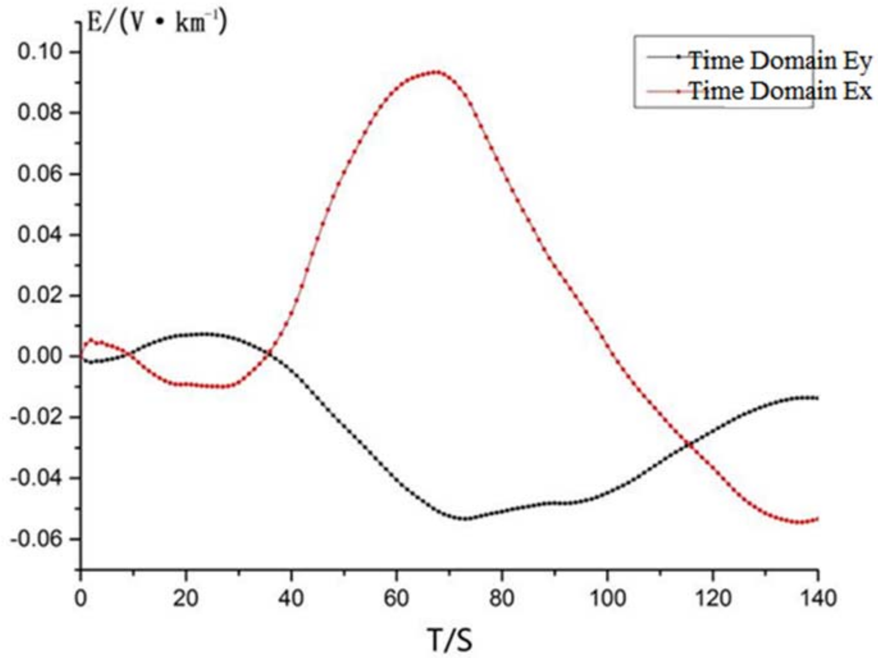

Figure 3. Calculation results of Rasiva's electric field intensity in time domain

Comparing with the time-domain results, the maximum Ex in frequency domain is 0.1 V/km, the relative error is 5%, the maximum Ey is 0.06 V/km, and the relative error is 2.8%. Therefore, the time-harmonic fitting method is used to calculate the electric field strength in China, and the calculation is simplified from the original time-domain calculation of multiple points to the frequency-domain calculation, which makes the calculation more simple and rapid.

3. Intensity distribution of actual pulse wide area geoelectric field

In the past, the uniform electric field of 1 V/km was often used to calculate the impact of magnetic storms on power grid, but the actual electric field intensity was not uniform and not necessarily 1 V/km. Such estimation would lead to large errors. In this paper, we choose the fast pulse of magnetic storm in 2004 to calculate the time harmonic combination. Because only high E-value magnetic storm pulses have a great impact on the power grid, because only high E-value magnetic storm pulses have a great impact on the power grid,] based on the field intensity map obtained by the geomagnetic field converter in reference [7], the pulses with Ex exceeding 15V/km and Ey exceeding 5V/km are selected for calculation.

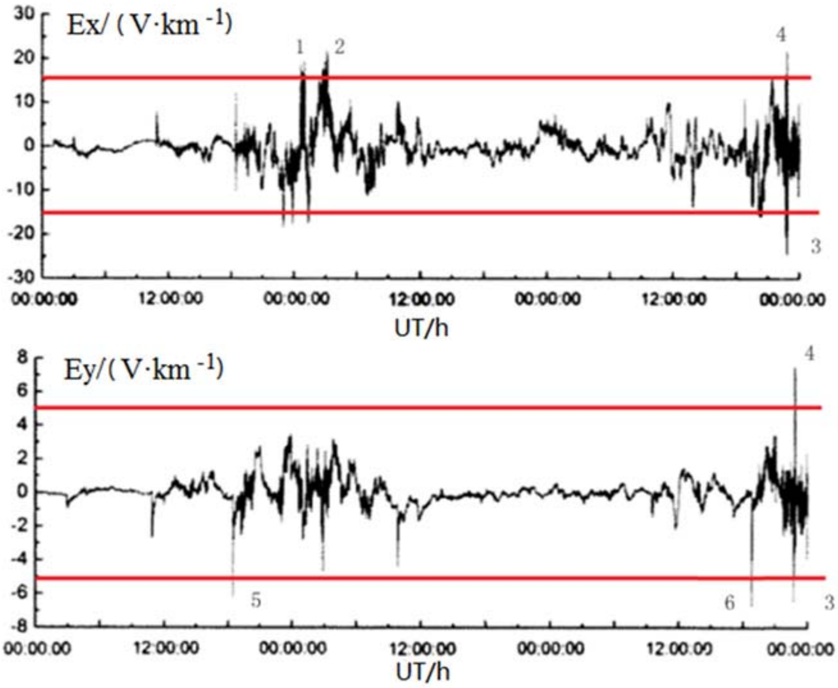

Figure 4. Selection of electric field intensity pulse for geomagnetic converter

Table 2. The start and stop time of the pulse selected by the magnetic storm

Pulse number	Pulse start and stop time
1	20041108T00:39:50-20041108T00:43:10
2	20041108T03:10:25-20041108T03:12:05
3	20041109T22:44:10-20041109T22:46:40
4	20041109T22:48:00-20041109T22:52:00
5	20041107T18:26:40-20041107T18:30:00
6	20041109T18:50:30-20041109T18:52:10

Figure4 is based on the data of Guangzhou Geomagnetic Observatory, so the data of Guangzhou Geomagnetic Observatory is selected to calculate the wide-area geoelectric field. Wide-area geomagnetic conductivity data are obtained from geomagnetic sounding in reference [9, 10], and the data are accurate and reliable. The real part is the intensity of the geoelectric field at one time, and the imaginary part is the value at another time. There is a quarter period difference between the two. Figure5 is the distribution of wide field geoelectric field under fourth pulses.

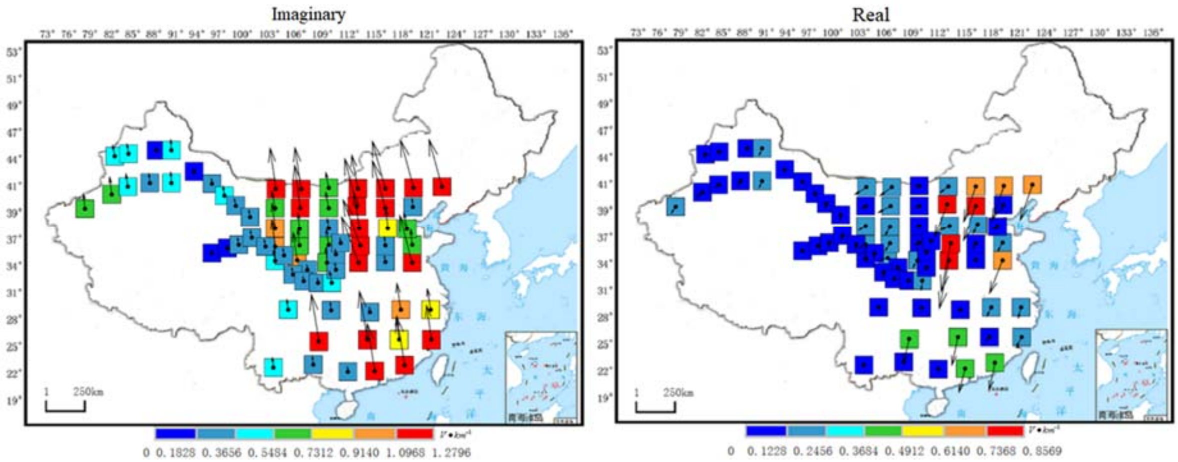

Figure 5. Fourth pulse electric field intensity E diagram

Figure5 shows that the intensity distribution of electric field in the whole country is very uneven. Under the fourth pulse, the maximum value of E is 0.625 V/km in the north-south direction and the minimum value is 10 mV/km in the North-South direction, and 0.223 V/km in the east-west direction and 1 mV/km in the East-West direction. At the other time, the maximum value of the imaginary part is 1.26 V/km in the North-South direction, the minimum value is 60 mV/km, the maximum value in the east-west direction is 0.2 V/km, and the minimum value is 10 mV/km. It can be seen that the difference between the maximum and minimum values is nearly 20 times, and the geoelectric field intensity in the north-south direction is greater than that in the East-West direction, indicating that the north-south direction of the grid is more likely to produce large GIC than the east-west direction of the grid.

4. Conclusion

(1) Time-harmonic fitting is used to simplify the time-domain problem into frequency-domain problem, which is proved to be more accurate by verification. And make computing fast and simple. It provides a relatively simple method for accurately studying the influence of magnetic storms on the power grid.

(2) The time-harmonic fitting method is used to analyze the variation of the national electric field intensity under the influence of the magnetic storm on November 7-9, 2004. It is found that the distribution of the national electric field intensity is very uneven, the maximum value is 1.3 V/km, and the minimum value is only 4 mV/km. Therefore, there is a big error when the uniform electric field intensity is used to calculate the GIC, and the regions should be considered when the magnetic storm occurs. The intensity of electric field.

(3) It is found that the influence of magnetic storms is more serious in North China and South China. Corresponding measures should be taken to reduce the impact of magnetic storms on power grid.

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